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Assessment of the Methodology for establishing the EU List of Critical Raw Materials

Annexes

Blengini, G.A., Blagoeva, D., Dewulf, J., Torres de Matos, C., Nita, V., Vidal-Legaz, B., Latunussa, C.E.L., Kayam, Y., Talens Peirò, L., Baranzelli, C., Manfredi, S., Mancini, L., Nuss, P., Marmier, A., Alves-Dias, P., Pavel, C., Tzimas, E., Mathieux, F., Pennington, D. and Ciupagea, C.

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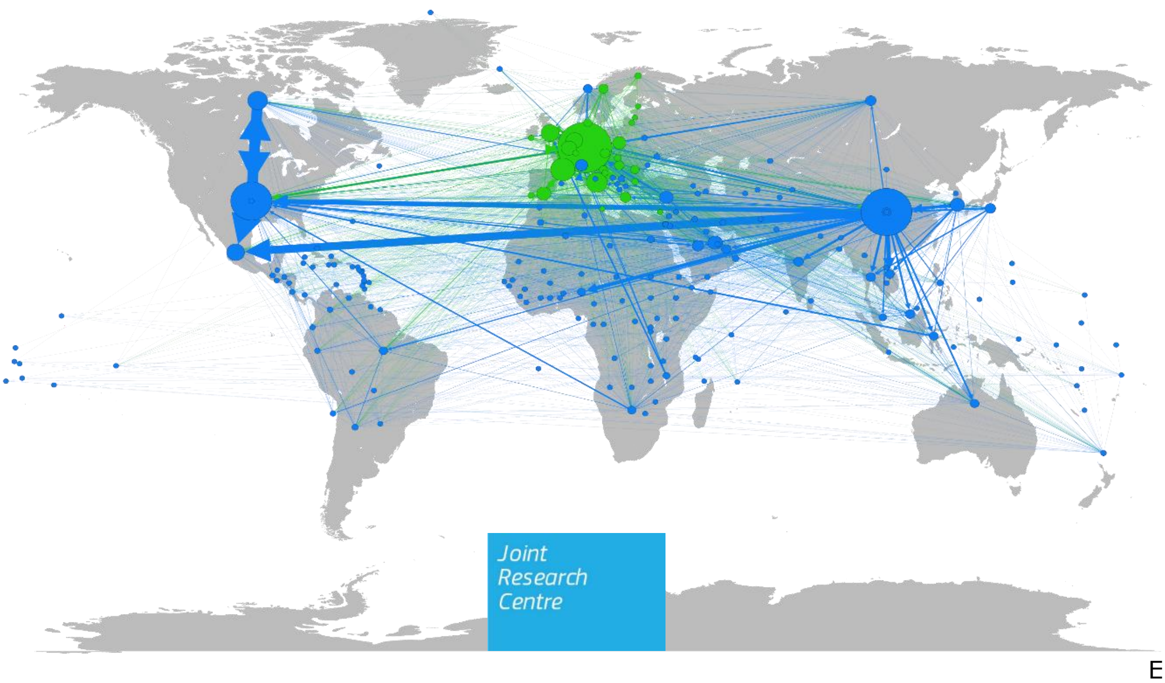

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1 ANNEX A: SUPPLY RISK

1.1 World Governance Index and Alternative Approaches

1.1.1 WGI data sources

In this section, the list of WGI data sources is provided. Then, two examples of data sources features are given in sections 1.1.2 and 1.1.3. It is important to note that the list of data sources used to compute each dimension may vary among countries because the country coverage is heterogeneous among data sources (e.g. global coverage, African coverage). Also, some data sources provide information for one single governance dimension (e.g. Transparency International, which provides information about Control of Corruption), while other sources provide information for more than one dimension (e.g. Afrobarometer, which provides information on four dimensions).

Country-specific information detailing the data sources used for the calculation of each governance dimension is available in the reports by country (http://info.worldbank.org/governance/wgi/index.aspx#countryReports).

Code	Source	Type*	Public	Country Coverage	Represe-ntative	1996	1998	2000	2002	2003	2004	2005	2006	2007	2008	2009
ADB	African Development Bank Country Policy and Institutional Assessments	Expert (GOV)	Partial	53			x	x	x	x	x	x	x	x	x	x
AFR	Afrobarometer	Survey	Yes	19				x	x	x	x	x	x	x	x	x
ASD	Asian Development Bank Country Policy and Institutional Assessments	Expert (GOV)	Partial	29				x	x	x	x	x	x	x	x	x
BPS	Business Enterprise Environment Survey	Survey	Yes	27				x	x	x	x	x	x	x	x	x
BTI	Bertelsmann Transformation Index	Expert (NGO)	Yes	125					x	x	x	x	x	x	x	x
CCR	Freedom House Countries at the Crossroads	Expert (NGO)	Yes	62							x	x	x	x	x	x
DRI	Global Insight Global Risk Service	Expert (CBIP)	Yes	144	x	x	x	x	x	x	x	x	x	x	x	x
EBR	European Bank for Reconstruction and Development Transition Report	Expert (GOV)	Yes	29		x	x	x	x	x	x	x	x	x	x	x
EIU	Economist Intelligence Unit Riskwire & Democracy Index	Expert (CBIP)	Yes	181	x	x	x	x	x	x	x	x	x	x	x	x
FRH	Freedom House	Expert (NGO)	Yes	197	x	x	x	x	x	x	x	x	x	x	x	x
GCB	Transparency International Global Corruption Barometer Survey	Survey	Yes	80					x	x	x	x	x	x	x	x
GCS	World Economic Forum Global Competitiveness Report	Survey	Yes	134	x	x	x	x	x	x	x	x	x	x	x	x
GII	Global Integrity Index	Expert (NGO)	Yes	79						x	x	x	x	x	x	x
GWP	Gallup World Poll	Survey	Yes	130	x								x	x	x	x
HER	Heritage Foundation Index of Economic Freedom	Expert (NGO)	Yes	179	x	x	x	x	x	x	x	x	x	x	x	x
HUM	Cingranelli Richards Human Rights Database and Political Terror Scale	Expert (GOV)	Yes	192	x	x	x	x	x	x	x	x	x	x	x	x
IFD	IFAD Rural Sector Performance Assessments	Expert (GOV)	Yes	90							x	x	x	x	x	x
IJT	iJET Country Security Risk Ratings	Expert (CBIP)	Yes	185	x						x	x	x	x	x	x
IPD	Institutional Profiles Database	Expert (GOV)	Yes	85	x								x	x	x	x
IRP	IREEP African Electoral Index	Expert (NGO)	Yes	53				x	x	x	x	x	x	x	x	x
LBO	Latinobarometro	Survey	Yes	18		x	x	x	x	x	x	x	x	x	x	x
MSI	International Research and Exchanges Board Media Sustainability Index	Expert (NGO)	Yes	76					x	x	x	x	x	x	x	x
OBI	International Budget Project Open Budget Index	Expert (NGO)	Yes	85								x	x	x	x	x
PIA	World Bank Country Policy and Institutional Assessments	Expert (GOV)	Partial	142		x	x	x	x	x	x	x	x	x	x	x
PRC	Political Economic Risk Consultancy Corruption in Asia Survey	Survey	Yes	15			x	x	x	x	x	x	x	x	x	x
PRS	Political Risk Services International Country Risk Guide	Expert (CBIP)	Yes	140	x	x	x	x	x	x	x	x	x	x	x	x
RSF	Reporters Without Borders Press Freedom Index	Expert (NGO)	Yes	170	x				x	x	x	x	x	x	x	x
TPR	US State Department Trafficking in People report	Expert (GOV)	Yes	153	x			x	x	x	x	x	x	x	x	x
VAB	Vanderbilt University Americas Barometer	Survey	Yes	23							x	x	x	x	x	x
WCY	Institute for Management and Development World Competitiveness Yearbook	Survey	Yes	55		x	x	x	x	x	x	x	x	x	x	x
WMO	Global Insight Business Conditions and Risk Indicators	Expert (CBIP)	Yes	203	x		x	x	x	x	x	x	x	x	x	x

*Types of Expert Assessments: CBIP -- Commercial Business Information Provider, GOV -- Public Sector Data Provider, NGO -- Nongovernmental Organization Data Provider

Source: Kaufmann D, Kraay A and Mastruzzi M. Policy Research Working Paper 4978. Governance Matters VIII. Aggregate and Individual Governance Indicators 1996–2008. The World Bank Development Research Group- Macroeconomics and Growth Team. June 2009.

1.1.2 Example of WGI data source contributing to one WGI dimension

Descriptive fiche of a WGI data source (Transparency International Global Corruption Barometer (GCB)) use for the computation of one WGI dimension (Control of Corruption). Only a selection of years is displayed.

Transparency International Global Corruption Barometer (GCB)

Data Provider	Transparency International
Description	Nongovernmental organization devoted to fighting corruption
Website	www.transparency.org
Data Source	Global Corruption Barometer
Type	Survey
Respondents	Households
Frequency	Annual since 2004
Coverage	Global sample of countries
Public Access	Country-level aggregate responses and some breakdowns are reported on TI's website
Description	This survey commissioned by TI collects data on households' experiences with corruption and their perceptions of the overall incidence of corruption. Note that we do NOT use data from the TI Corruption Perceptions Index. This is a composite indicator of corruption based on an aggregation of a subset of the data sources that we use in our Control of Corruption indicator. Note that in each year we carry forward scores for those countries that were covered in earlier years (up to two) but not in current year.

	2013	2012	2011	2010
Voice and Accountability				
NA	..	..	..	..
Political Stability and Absence of Violence				
NA	..	..	..	..
Government Effectiveness				
NA	..	..	..	..
Regulatory Quality				
NA	..	..	..	..
Rule of Law				
NA	..	..	..	..
Control of Corruption				
Frequency of household bribery - paid a bribe to one of the 8/9 services below	X	X	X	X
Frequency of bribes paid to following institution - education	X	X	X	X
Frequency of bribes paid to following institution - judiciary	X	X	X	X
Frequency of bribes paid to following institution - medical	X	X	X	X
Frequency of bribes paid to following institution - police	X	X	X	X
Frequency of bribes paid to following institution - permit	X	X	X	X
Frequency of bribes paid to following institution - utilities	X	X	X	X
Frequency of bribes paid to following institution - tax	X	X	X	X
Frequency of bribes paid to following institution - land	X	X	X	X
Frequency of bribes paid to following institution - customs	..	..	X	X
Frequency of corruption among public institutions: Political parties	X	X	X	X

		Frequency of corruption among public institutions: Parliament/Legislature	X	X	X	X
		Frequency of corruption among public institutions: Media	X	X	X	X
		Frequency of corruption among public institutions: Legal system/Judiciary	X	X	X	X
		Frequency of corruption among public institutions: Public officials*	X	X	X	X
		Frequency of corruption among public institutions: The military	..	..	..	..
		Frequency of corruption among public institutions: Education system	..	..	..	..
		Frequency of corruption among public institutions: Police	..	..	..	..
		Frequency of corruption among public institutions: Registry and permit services	..	..	..	..
		Frequency of corruption among public institutions: Tax revenue	..	..	..	..
		Frequency of corruption among public institutions: Medical services	..	..	..	..
		Frequency of corruption among public institutions: Utilities (telephone, electricity, water, etc.)	..	..	..	..
		Country coverage *	114	114	103	103
		Year of Publication	**2013**	**2013**	**2011**	**2011**

Source: World Bank, 2014. Excel sheet of WGI data sources, http://info.worldbank.org/governance/wgi/index.aspx#doc-sources

1.1.3 Example of WGI data source contributing to several WGI dimensions

Descriptive fiche of a WGI data source (African Eurobarometer) contributing to the calculation of several WGI dimensions. Only a selection of years is displayed.

	Afrobarometer (AFR)				
Data Provider	Michigan State University; Institute for Democracy (South Africa); Centre for Democracy and Development (Ghana).				
Description	U.S-based university and African non-governmental organization				
Website	www.afrobarometer.org				
Data Source	Afrobarometer surveys				
Type	Survey				
Respondents	Households				
Frequency	Approximately every three years since 1999.				
Coverage	African countries				
Public Access	Country level aggregates are publicly available through Afrobarometer website. Record-level data is released with some lag through the Inter-University Consortium for Political and Social Research (www.icpsr.org).				
Description	This household survey is designed to collect data on attitudes towards democracy and government in a sample of different African countries. We do not use data from the 1999 survey as the questionnaire from this year differs substantially from subsequent years, covering only a fraction of questions relevant to the WGI for following years. The indices range from 0 to 1 (good).				
		2013	2012	2011	2010
	Voice and Accountability				
	How much do you trust the parliament?	X	X	X	X
	Overall, how satisfied are you with the way democracy works in your country?	X	X	X	X
	Free and fair elections	X	X	X	X
	Political Stability and Absence of Violence				
	NA	..	..	..	..
	Government Effectiveness				
	Government handling of public services (health, education)	X	X	X	X
	Regulatory Quality				
	NA	..	..	..	..
	Rule of Law				
	Over the past year, how often have you or anyone in your family feared crime in your own home?	X	X	X	X
	Over the past year, how often have you or anyone in your family had something stolen from your house?	X	X	X	X
	Over the past year, how often have you or anyone in your family been physically attacked?	X	X	X	X
	How much do you trust the courts of law?	X	X	X	X
	Trust in police	X	X	X	X
	Control of Corruption				

	How many elected leaders (parliamentarians) do you think are involved in corruption?	X	X	X	X
	How many judges and magistrates do you think are involved in corruption?	X	X	X	X
	How many government officials do you think are involved in corruption?	X	X	X	X
	How many border/tax officials do you think are involved in corruption?	X	X	X	X
	Country Coverage	**33**	**33**	**33**	**20**
	Year of Publication	**2013**	**2013**	**2013**	**2008**

Source: World Bank, 2014. Excel sheet of WGI data sources, http://info.worldbank.org/governance/wgi/index.aspx#doc-sources

1.1.4 Production of raw materials in countries not covered by PPI

Country	Material	Sum of % of global supply
ALGERIA	Phosphate rock	12.0%
ARMENIA	Molybdenum	1.7%
	Perlite	2.0%
	Rhenium	1.2%
AUSTRIA	Limestone	3.4%
	Magnesite	4.0%
	Pulpwood	0.9%
	Sawn softwood	3.0%
	Talc	1.8%
	Tungsten	1.5%
BAHRAIN	Aluminium	2.1%
BELARUS	Potash	16.3%
BELGIUM	Indium	4.5%
	Selenium	5.6%
	Silica sand	1.3%
	Tellurium	13.0%
BOSNIA AND HERZEGOVINA	Bauxite	0.3%
CAMEROON	Aluminium	0.2%
CROATIA	Limestone	0.1%
CUBA	Cobalt	3.4%
	Nickel	3.6%
CYPRUS	Bentonite	1.2%
CZECH REPUBLIC	Bentonite	1.3%
	Clays	12.1%
	Diatomite	1.9%
	Sawn softwood	1.0%
	Silica sand	1.0%
DENMARK	Diatomite	9.7%
GABON	Manganese	10.0%
GEORGIA	Perlite	2.5%
GERMANY	Bentonite	2.6%
	Clays	15.9%
	Fluorspar	1.0%
	Gallium	10.0%
	Limestone	3.3%
	Potash	8.7%
	Pulpwood	1.4%
	Sawn softwood	7.0%
	Selenium	9.4%
	Silica sand	5.4%
	Silicon metal	2.0%
	Tellurium	8.0%
ICELAND	Aluminium	2.0%
IRAN, ISLAMIC REP.	Barytes	3.4%
	Bentonite	3.9%
	Borate	0.0%
	Clays	2.6%
	Feldspar	2.4%
	Gypsum	13.1%
	Molybdenum	2.7%
	Perlite	1.7%
	Silica sand	1.1%
ISRAEL	Magnesium	3.9%

	Phosphate rock	2.0%
	Potash	5.5%
ITALY	Cork	3.0%
	Feldspar	22.8%
	Gypsum	2.9%
	Limestone	2.3%
	Perlite	3.4%
	Silica sand	14.1%
	Talc	1.9%
JAMAICA	Bauxite	4.9%
JAPAN	Bentonite	3.1%
	Feldspar	3.2%
	Gallium	2.0%
	Gypsum	4.1%
	Indium	10.5%
	Limestone	2.4%
	Perlite	17.0%
	Pulpwood	4.7%
	Sawn softwood	3.0%
	Selenium	18.0%
	Silica sand	2.1%
	Talc	4.8%
	Tellurium	14.0%
JORDAN	Phosphate rock	4.0%
	Potash	4.1%
KOREA, DEM. REP.	Natural graphite	3.0%
KOREA, REP.	Clays	3.3%
	Feldspar	2.9%
	Gallium	4.0%
	Indium	10.5%
	Limestone	2.2%
	Rhenium	1.0%
	Sawn softwood	1.0%
	Selenium	3.8%
	Talc	9.6%
	Tellurium	4.0%
LATVIA	Silica sand	1.0%
MACEDONIA, FYR	Zinc	0.3%
MONTENEGRO	Aluminium	0.2%
NEW CALEDONIA	Cobalt	3.2%
OMAN	Chromium	2.0%
PAKISTAN	Barytes	0.7%
	Chromium	2.0%
RWANDA	Tantalum	16.2%
SAUDI ARABIA	Feldspar	2.4%
SLOVAK REPUBLIC	Magnesite	6.0%
	Perlite	1.4%
SRI LANKA	Natural graphite	1.0%
	Natural rubber	1.0%
SYRIAN ARAB REPUBLIC	Phosphate rock	2.0%
TAJIKISTAN	Antimony	3.0%
TUNISIA	Cork	3.0%
	Phosphate rock	4.0%
UKRAINE	Clays	4.8%
	Coking coal	2.0%
	Gallium	4.0%
	Hafnium	3.1%
	Iron ore	3.9%
	Magnesium	0.3%
	Manganese	3.2%

	Titanium	6.6%
UNITED ARAB EMIRATES	Aluminium	3.4%
UNITED KINGDOM	Clays	3.5%
	Fluorspar	0.5%
	Potash	1.3%
	Sawn softwood	1.0%
	Silica sand	2.7%
UZBEKISTAN	Gold	3.5%
	Rhenium	5.8%

Source: our elaboration based on PPI data (Fraser Institute, 2015. Survey of Mining Companies 2014, https://www.fraserinstitute.org/research-news/display.aspx?id=22259, and global production data (2013 criticality study).

1.1.5 Sensitivity of supply risk calculation to PPI missing values

The impact of PPI missing values for some producing countries on the results of supply risk calculation of candidate materials has been analysed. It was found an overall low sensitivity.

Methodology and results:

In the methodology proposed by Graedel et al., 2012, the limited coverage of the PPI was overcome by imputing the values for countries that did not have a PPI estimate. There, a value of 50 was assigned when PPI was missing. Then the sensitivity of supply risks results to this imputation was analysed (see Supplementary Material of Graedel et al., 2012).

Here, an assessment of the impact of PPI missing values imputation on supply risk was undergone. We used data from the last PPI release (Fraser Institute, 2015), which corresponds to year 2014. Then, supply risk was calculated using different imputed values for PPI missing values and results were compared.

Three calculations were implemented: i) imputation of missing values by a value of 50, ii) by a value of 40 (i.e. 20% reduction of initial imputed value), iii) imputation by a value of 60 (20% increase). Sensitivity coefficients of supply risk results were calculated to assess how much supply risk would change when changing PPI imputed value, i.e. the ratio between the relative change of supply risk and the relative change of PPI value (20% up or down). Sensitivity coefficients above 1 would mean that the impact of changes in PPI imputed values on supply risk is high. This would therefore indicate that a robust methodology would be essential to rely on the supply risk results when using PPI instead of WGI.

In the table below results of this sensitivity analysis are displayed. There supply risk results using different imputed values for PPI missing values are displayed, and accompanied by the supply risk calculation without any data imputation (for comparability purpose). Sensitivity coefficients are also provided.

The analysis showed, overall, the low sensitivity of supply risk to imputation of PPI missing values. The highest sensitivity values were found for tantalum. Although analyses here conclude that it is unlikely that supply risk results would experience relevant changes due to PPI missing values, a robust methodology should be always followed to impute PPI missing values. A suitable approach for that could be the imputation of missing values based on average PPI values of neighbour countries, given they had similar socio-political conditions. Another alternative for that would be to impute PPI values supported by the list of countries ranked according to WGI.

Material	Supply risk, PPI, missing values not imputed	Supply risk, PPI, missing values imputed with 5	Supply risk, PPI, missing values imputed with 4	Supply risk, PPI, missing values imputed with 6	Sensitivity coefficient
REE (heavy)	5.96	5.96	5.96	5.96	0.00
REE (light)	4.05	4.05	4.05	4.05	0.00
Niobium	3.48	3.48	3.48	3.48	0.00
Antimony	3.47	3.47	3.47	3.47	0.00
Magnesium	3.17	3.18	3.18	3.18	0.00
Natural graphite	2.75	2.75	2.75	2.75	0.00
Magnesite	2.75	2.78	2.77	2.79	0.01
Tungsten	2.53	4.74	4.30	5.18	0.47
Germanium	2.46	2.46	2.46	2.46	0.00
Gallium	2.27	2.31	2.31	2.32	0.02
Indium	2.21	2.32	2.30	2.34	0.05
Fluorspar	2.16	2.17	2.17	2.18	0.00
Barytes	2.15	2.16	2.16	2.16	0.01
Silicon metal	2.14	2.14	2.14	2.14	0.00
Beryllium	1.77	1.77	1.77	1.77	0.00
Coking coal	1.63	1.64	1.64	1.64	0.00
Scandium	1.52	1.52	1.52	1.52	0.00
Phosphate rock	1.42	1.42	1.42	1.42	0.00
Cobalt	1.33	1.36	1.35	1.36	0.02
PGMs	1.32	1.37	1.36	1.38	0.04
Tin	1.17	1.17	1.17	1.17	0.00
Chromium	1.16	1.17	1.17	1.18	0.01
Molybdenum	1.07	1.07	1.07	1.07	0.00
Borate	1.06	1.06	1.06	1.06	0.00
Vanadium	1.00	1.00	1.00	1.00	0.00
Bauxite	0.79	0.80	0.80	0.80	0.01
Cork	0.79	0.80	0.80	0.80	0.01
Rhenium	0.78	0.80	0.80	0.80	0.02
Lithium	0.77	0.77	0.77	0.77	0.00
Iron ore	0.65	0.67	0.66	0.67	0.02
Hafnium	0.57	0.57	0.57	0.57	0.00
Zinc	0.56	0.57	0.57	0.57	0.01
Aluminium	0.54	0.58	0.58	0.59	0.07
Manganese	0.48	0.53	0.52	0.54	0.09
Limestone	0.47	0.67	0.63	0.71	0.30
Bentonite	0.45	0.47	0.47	0.47	0.04
Gypsum	0.43	0.69	0.64	0.74	0.37
Tantalum	0.36	0.85	0.75	0.95	0.58
Perlite	0.34	0.40	0.39	0.41	0.16
Nickel	0.31	0.36	0.35	0.37	0.14
Silver	0.29	0.37	0.35	0.38	0.20
Silica sand	0.29	0.42	0.39	0.44	0.29
Talc	0.29	0.32	0.31	0.32	0.09
Diatomite	0.29	0.30	0.30	0.31	0.05
Feldspar	0.25	0.47	0.43	0.52	0.47
Copper	0.23	0.28	0.27	0.29	0.17
Clays	0.21	0.42	0.38	0.46	0.49
Gold	0.17	0.29	0.26	0.31	0.39
Titanium	0.17	0.17	0.17	0.18	0.05
Selenium	0.16	0.27	0.25	0.29	0.40

Potash	0.16	0.22	0.21	0.23	0.28
Tellurium	0.14	0.27	0.25	0.30	0.47

Note 1: values are ordered based on values of the first column (PPI with missing values not imputed).

Note 2: Results for natural rubber, sawn softwood and pulpwood are not provided, since the use of PPI is not suitable for its use with biotic materials.

1.1.6 References

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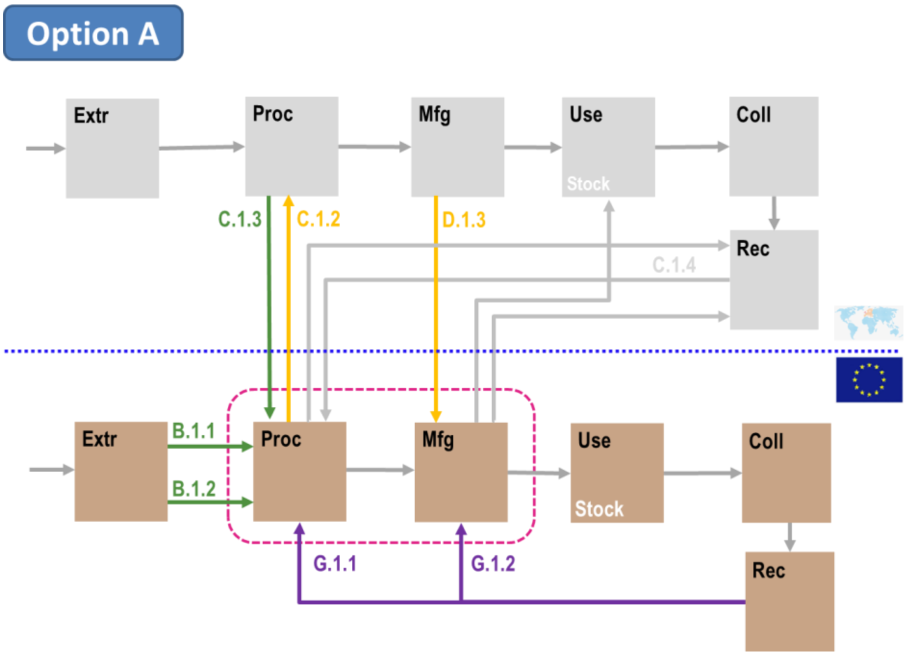
1.2 Recycling

1.2.1 Options to calculate EOL-RIR using the MSA study.

Streamlined Approach (Option A)

Option A is the streamlined option for quick calculation. It takes into account the 'net import' (i.e. C.1.3 import and C.1.2 export flows) to the processing stage. Imports of secondary materials (C.1.4) are not included in the calculation. When the import of secondary material is high (i.e. Rhodium), a correction must be introduced.



Green: primary material; Yellow: processed material; Purple: secondary material.

$$EOL - RIR_A = \frac{G.1.1 + G.1.2}{B.1.1 + B.1.2 + (C.1.3 - C.1.2) + D.1.3 + G.1.1 + G.1.2}$$

Where the MSA flows accounted for are:

B.1.1. *Production of primary material as main product in EU sent to processing in EU;*

B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU;*

C.1.2 *Exports from EU of processed material;*

C.1.3 *Imports to EU of primary material;*

D.1.3 *Imports to EU of processed material;*

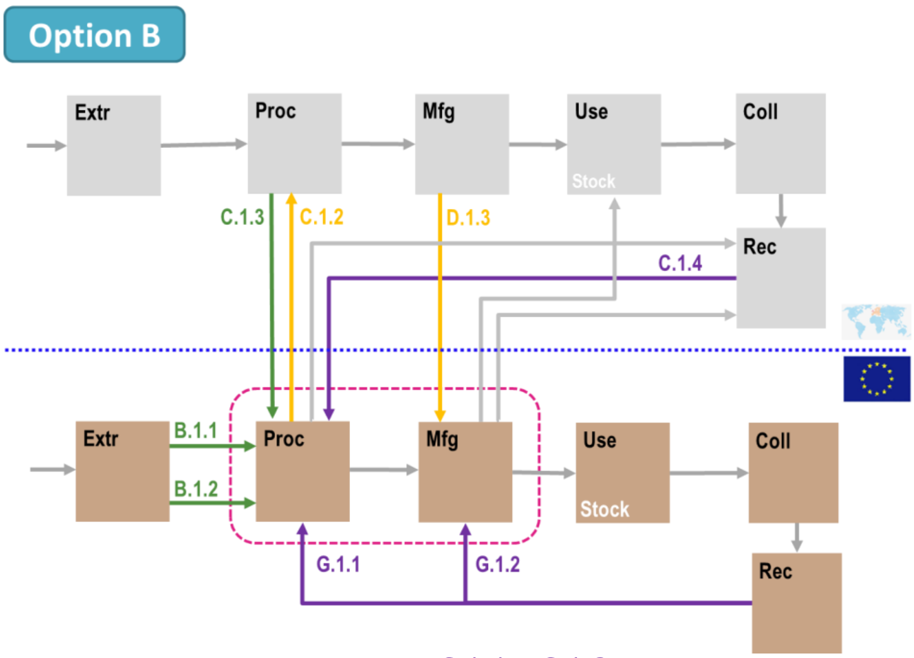
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU;*

G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU.*

Net Import Approach (Option B)

Option B takes into account the 'net import' (i.e. C.1.3 import and C.1.2 export flows) to the processing stage. Imports of secondary materials (C.1.4) are included in the calculation as imports (only in the denominator). This option is based on the assumption that the raw material that leaves the EU (at the processing stage) is not contributing to EU manufacturing (i.e. no added value and jobs downstream).

Green: primary material; Yellow: processed material; Purple: secondary material.



$$EOL - RIR_B = \frac{G.1.1 + G.1.2}{B.1.1 + B.1.2 + (C.1.3 - C.1.2) + D.1.3 + C.1.4 + G.1.1 + G.1.2}$$

Where the MSA flows accounted for are:

B.1.1. *Production of primary material as main product in EU sent to processing in EU;*

B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU;*

C.1.2 *Exports from EU of processed material;*

C.1.3 *Imports to EU of primary material;*

C.1.4. *Import to the EU of secondary materials;*

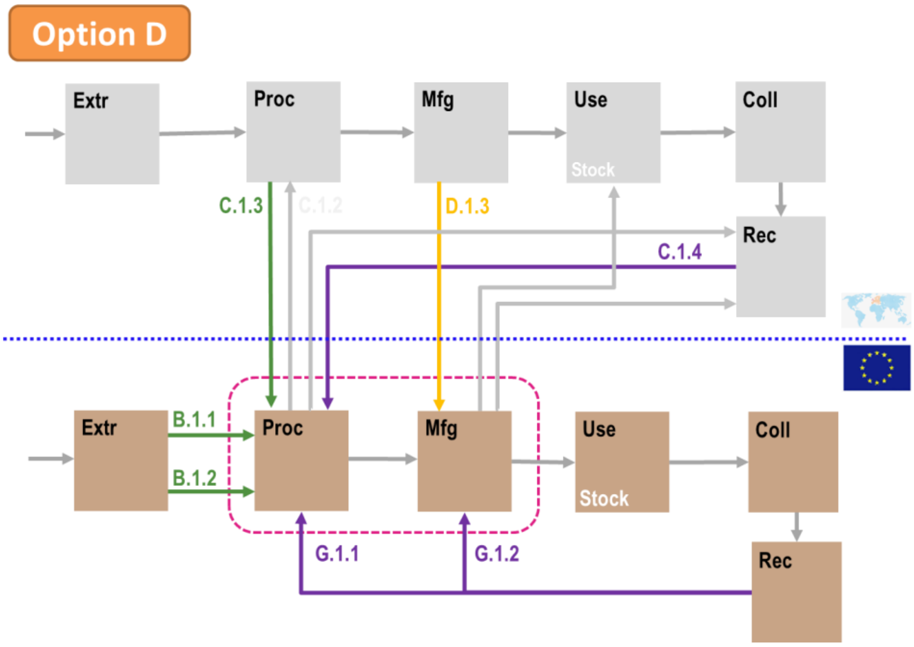
D.1.3 *Imports to EU of processed material;*

G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU;*

G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU.*

Gross Import + Imported Secondary Materials (Option D)

Option D is similar to option C, but in addition, it considers the imported secondary material flow (C.1.4) as an input of secondary materials, thus it contributes to reduce the risk (C.1.4 is included in the numerator and denominator). The underlying assumption is that the contribution of imported secondary materials is riskless, which is very unlikely. A disadvantage is the low comparability with data given in the UNEP's study on metals, which is the second data source proposed in this revision of the method.



Green: primary material; Yellow: processed material; Purple: secondary material.

$$EOL - RIR_D = \frac{G.1.1 + G.1.2 + C.1.4}{B.1.1 + B.1.2 + C.1.3 + D.1.3 + C.1.4 + G.1.1 + G.1.2}$$

Where the MSA flows accounted for are:

B.1.1. *Production of primary material as main product in EU sent to processing in EU;*

B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU;*

C.1.3 *Imports to EU of primary material;*

C.1.4. *Import to the EU of secondary materials;*

D.1.3 *Imports to EU of processed material;*

G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU;*

G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU.*

1.2.2 End of life recycling input rate (EOL-RIR) used in the 2013 EC criticality study, values obtained using the MSA study (including options A to D) and UNEP data.[1]

Materials	EC study 2013	MSA study 2015				UNEP report 2011
		Option A	Option B	Option C	Option D	
Aggregates	n.i	7	7	7	7	n.i
Aluminium	35	-	-	-	-	16
Antimony	11	28	28	28	28	7
Barytes	0	-	-	-	-	n.i
Bauxite	0	-	-	-	-	n.i
Bentonite	0	-	-	-	-	n.i
Beryllium	19	0	0	0	0	8
Borate	0	1	1	1	1	n.i
Chromium	13	30	28	21	25	13
Clays	0	-	-	-	-	n.i
Cobalt	16	47	47	35	35	16
Coking coal	0	0	0	0	0	n.i
Copper	20	-	-	-	-	15
Diatomite	0	-	-	-	-	n.i
Feldspar	0	-	-	-	-	n.i
Fluorspar	0	1	1	1	1	n.i
Gallium	0	0	0	0	1	0
Germanium	0	2	2	2	2	9
Gold	25	-	-	-	-	23
Gypsum	1	-	-	-	-	n.i
Hafnium	0	-	-	-	-	n.d.
Indium	0	0	0	0	4	0
Iron	22	-	-	-	-	24
Lead	n.i	-	-	-	-	50
Limestone	0	-	-	-	-	n.i
Lithium	0	0	0	0	0	0
Magnesite	0	2	2	2	2	n.i
Magnesium	14	13	13	13	13	14
Manganese	19	-	-	-	-	19
Molybdenum	17	-	-	-	-	17
Natural Graphite	0	3	3	3	3	n.i
Natural Rubber	0	-	-	-	-	-
Nickel	32	-	-	-	-	26
Niobium	11	0	0	0	0	11
Perlite	0	-	-	-	-	n.i
Phosphate Rock	0	17	17	17	17	n.i
Potash	0	-	-	-	-	n.i
Pulpwood	51	-	-	-	-	n.i

[1] Option C refers to the approach chosen in the background report.

Materials	EC study 2013	MSA study 2015				UNEP report 2011
		Option A	Option B	Option C	Option D	
Rhenium	13	-	-	-	-	9
Sawn Softwood	9	-	-	-	-	n.i
Scandium	1	-	-	-	-	n.d.
Selenium	5	-	-	-	-	n.d.
Silica sand	24					n.i
Silicon	0	0	0	0	0	n.i
Silver	24	-	-	-	-	21
Talc	0	-	-	-	-	n.i
Tantalum	4	-	-	-	-	3
Tellurium	0	-	-	-	-	n.d.
Tin	11	-	-	-	-	11
Titanium	6	-	-	-	-	6
Tungsten	37	42	42	42	42	37
Vanadium	0	-	-	-	-	n.d.
Zinc	8	-	-	-	-	9
PGMs	35	-	-	-	-	-
Platinum		24	18	11	23	23
Palladium		24	15	9	25	40
Rhodium		129	21	9	39	32
Ruthenium		-	-	-	-	11
Iridium		-	-	-	-	14
Osmium		-	-	-	-	
REE (Heavy)	0	-	-	-	-	-
Terbium		28	28	22	22	
Dysprosium		0	0	0	0	
Erbium		0	0	0	0	
Yttrium		43	43	31	31	
REE (Light)	0	-	-	-	-	-
Lanthanum		-	-	-	-	
Cerium		-	-	-	-	
Praseodymium		-	-	-	-	
Neodymium		1	1	1	1	
Samarium		-	-	-	-	
Europium		56	56	38	38	
Gadolinium		-	-	-	-	

n.d: no data available; n.i.: not included.

1.2.3 End of life recycling input rate (EOL-RIR) for industrial minerals calculated using IMA 2013 data.

Recyclates obtained from industrial minerals are frequently used for other functions and applications than those for virgin primary materials. In order to understand better the amounts of secondary materials that are effectively back to substitute virgin primary materials and therefore contribute to the total supply, data need to be analysed in further detail. The EU Industrial minerals association (IMA) has published a report that includes recycling rates and information about the end-use of the recyclates obtained from some industrial minerals materials (European Industrial Minerals Association 2013). Based on the information published, JRC has distinguished between functional and non-functional recycling, and provided an estimate of EOL-RIR. The table below shows the example of bentonite. For bentonite, recycling into new paper grade is accounted for as functional recycling whereas energy recovery by incineration is considered to be non-functional recycling. The IMA report states that about 70% of paper is recycled: 40% into new paper grades; 30% incinerated and 30% landfill.

Bentonite							
	End use (first)		**Recycling**		**End use (second)**		**Recycling rate**
	Type	**%**	**Process**	**Recyclate**	**Type**	**%**	**%**
Functional recycling	Civil engineering	11	Bentonite is used in several civil engineering applications	Construction materials	Concrete bricks and tiles; asphalt; wood, glass, metals, plastics, gypsum; dredging soil, soil and track ballast; other mineral and construction and demolition waste	60	6.6
	Paper	4	Recycling of paper	Recycled paper	New paper grades	40	1.6
	Total functional recycling (EOL-RIR)						**8.2**
Non-functional recycling	Pet litter	29	Incineration together with municipal waste	Fly ash	Several industries as wall board industry	20	5.8
	Foundry Molding Sands	24	Bentonite contain in foundry sand is regenerated after metal casting	Not specified	Construction industry	80	19.2
	Pelletizing of iron ore	21	Bentonite transferred to the slag phase	Not specified	Cement industry	70	14.7
	Paper	4	Incineration together with municipal waste	Fly ash	Several industries as wall board industry	30	1.2
	Others	11	-	-	-	0	0
	Total non-functional recycling						**40.9**
Total recycling (functional and non-functional)							**49.1**

The report states that about 70% of paper is recycled: 40% into new paper grades; 30% incinerated and 30% landfill. In the table above, recycling into new paper grade is accounted for as functional recycling; the energy recovery by incineration is considered to be non-functional recycling.

Calcium carbonate (limestone)								
	End use (first)		Recycling		End use (second)		EOL-RIR
	Type	%	Process	Recyclate	Type	%	%
Functional recycling	Paper*	40	Recycling of paper	Recycled paper	New paper grades	40	16
	Container glass	15	Recycling of glass	Recycled glass	New glass products	68	10.2
	Total functional recycling						**26.2**
Non-functional recycling	Paper	40	Incineration together with municipal waste	Fly ash	Several industries as wall board industry	30	12
	Plastics	15	-	Construction materials	Several products	17.5*	2.6
	Paints and coatings	15	Bentonite contain in foundry sand is regenerated after metal casting	Aggregates and construction materials	Construction industry	55**	8.2
	Container glass	15	Not detailed	Construction related	Construction industry	7	1.1
	Reagent in flue gas treatment	8	Incineration together with municipal waste	gypsum	Construction industry; underground mining; restoration of open cast mines, quarries and pits	90.5	7.2
	Others	7	-	-	-	0	0
	Total non-functional recycling						**31.1**
Total recycling (functional and non-functional)							**57.3**

*Average value estimated of 15-20% values reported. ** Average value estimated of 50-60% values reported.

Feldspar							
	End use (first)		Recycling		End use (second)		EOL-RIR
	Type	%	Process	Recyclate	Type	%	%
Functional recycling	Container glass	30	Recycling of glass	Recycled glass	New glass products	68	20.4
	Flat glass	30	Recycling glass	Recycled glass	New container glass	40*	12
	Total functional recycling						**32.4**
Non-functional recycling	Container glass	30	Not detailed	Construction related	Construction industry	7	2.1
	Flat glass	30	Recycling glass	Construction materials	Construction applications as engineered stones and others	40*	12
	Ceramics	35	Not detailed	Aggregates and other construction materials	Construction industry	60	21
	Others	7	-	-	-	0	0
	Total non-functional recycling						**35.1**
Total recycling (functional and non-functional)							**67.5**

*We assume that 50% of the recyclate from flat glass is used as container glass, and 50% for construction applications.

Kaolin and clays							
	End use (first)		Recycling		End use (second)		EOL-RIR
	Type	%	Process	Recyclate	Type	%	
Functional recycling	Paper	17	Recycling of paper	Recycled paper	New paper grades	40	6.8
	Fiberglass (in reinforced plastics)	1	Recycling of plastics	Recycled reinforced plastics	New reinforced plastics	20	0.2
	Total functional recycling						7
Non-functional recycling	Paper	17	Incineration together with municipal waste	Fly ash	Several industries as wall board industry	30	5.1
	Ceramics	60	Not detailed	Aggregates and other construction materials	Construction industry	60	36
	Fiberglass (in composites)	4	-	-	-	0	0
	Others	11	-	-	-	0	0
	Total non-functional recycling						41.1
Total recycling (functional and non-functional)							48.1

Notes: The report states that about 70% of paper is recycled: 40% into new paper grades; 30% incinerated and 30% landfill. In the table above, recycling into new paper grade is accounted for as functional recycling; the energy recovery by incineration is considered to be non-functional recycling. The table does also a difference between the fiberglass contained in reinforced plastics, which is generally recycled (it represents 20% of all fiberglass uses); and fiberglass in composites not presently recycled.

Talc							
	End use (first)		Recycling		End use (second)		EOL-RIR
	Type	%	Process	Recyclate	Type	%	
Functional recycling	Paper	29	Recycling of paper	Recycled paper	New paper grades	40	11.6
	Polymers for car industry	21	Recycling of plastics	Recycled plastics	New plastics for under-the-bonnet automotive parts, arch liners, cable harness plugs, water and sewage pipes, furniture feet, chair arms rests and electric motor housing	95	20
	Total functional recycling						**31.6**
Non-functional recycling	Paper	29	Incineration together with municipal waste	Fly ash	Several industries as wall board industry	30	8.7
	Ceramics	15	Not detailed	Aggregates and other construction materials	Construction industry	60	9
	Paints and coatings	19	Bentonite contain in foundry sand is regenerated after metal casting	Aggregates and construction materials	Construction industry	55**	11.4
	Others	16	-	-	-	0	0
	Total non-functional recycling						**29.1**
Total recycling (functional and non-functional)							**60.7**

Notes: The report states that about 70% of paper is recycled: 40% into new paper grades; 30% incinerated and 30% landfill. In the table above, recycling into new paper grade is accounted for as functional recycling; the energy recovery by incineration is considered to be non-functional recycling.

Silica sand							
	End use (first)		Recycling		End use (second)		EOL-RIR
	Type	%	Process	Recyclate	Type	%	
Functional recycling	Construction and soil	39	Recycling of construction materials	Recycled aggregate	Concrete, asphalt and landfill ground levelling	85	33.2
	Container glass	17	Recycling of glass	Recycled glass	New glass products	68	11.6
	Flat glass	17	Recycling glass	Recycled glass	New container glass	40*	6.8
	Glass (other)	5	Recycling of low-end glass application	Recycled low-end glass	Glass wool; glass foam;	25	1.3
	Total functional recycling						52.9
Non-functional recycling	Container glass	17	Not detailed	Construction related	Construction industry	7	1.2
	Flat glass	17	Recycling glass	Construction materials	Construction applications as engineered stones and others	40*	6.8
	Foundry	12	Recycling of foundry sand	Construction material	Construction industry	80	9.6
	Ceramics	4	Not detailed	Aggregates and other construction materials	Construction industry	60	2.4
	Others	6	-	-	-	0	0
	Total non-functional recycling						20
Total recycling (functional and non-functional)							72.9

1.2.4 References

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IMA. 2013. Recycling Industrial Minerals. Brussels: Industrial Minerals Association (IMA). http://www.ima-europe.eu/sites/ima-europe.eu/files/publications/IMA%20Recycling%20Sheets%20FULL%20published%20on%2024.10.2013_0.pdf. Accessed February 22, 2016.

UNEP. 2011. Recycling Rates of Metals - A Status Report. A Report of the Working Group on the Global Metal Flows to the International Resource Panel. Paris: United Nations Environment Programme (UNEP). http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals_Recycling_Rates_110412-1.pdf. Accessed July 23, 2014.

2 ANNEX B : ANALYSIS OF DATA AVAILABILITY AND QUALITY

2.1 Evaluation matrix for data quality assessment

	Geographical coverage	**Data completeness (supply chain / methodology indicators coverage)**	**Time resolution/ frequency of update**	**Level of aggregation of data**	**Forecast data & other data (e.g. market size etc.) availability**	**Data access (cost and conditions for data use)**	**Source type**
2	Very strong coverage *(most of the countries worldwide)*	Very strong coverage *(most of the supply chain steps for a certain material present)*	Data available for time series and updated at regular intervals	Data available for high level of detail and disaggregation	Very ample coverage *(e.g. – short, medium and long term forecast data is available, e.g. 2020, 2030, 2050)*	Free data source	Public source + European data
1	Satisfactory coverage *(Most countries in Europe and/or significant number of countries worldwide)*	Satisfactory coverage *(few steps in the supply chain data present)*	No meaningful time series due to poor regularity of updates	Data available for satisfactory level of detail and disaggregation	Satisfactory coverage *(e.g. – only short term forecast data available)*	Small access fee to be paid - up to e.g. < 400 €	Public source
0	Limited coverage *(Data available for limited number of countries)*	Restricted coverage *(data available for only one step of the supply chain)*	Very random updates; data available only for few years	Disaggregation is very limited due to very poor level of details	Limited coverage or no forecast data available	Paid data access	Private/corporate data

Max score 14 = very high quality data

Min score 0 = very poor quality data

Scores between 0 and 4 = low quality data

Scores between 5 and 9 = medium quality data

Scores between 10 and 14 = high quality data

2.1.1 Data evaluation for Li: Panorama 2010 du marché du Lithium

https://halshs.archives-ouvertes.fr/halshs-00809298/document

Criteria score	Geographical coverage	Data completeness	Time resolution/ frequency of update	Level of aggregation of data	Forecast data & other data	Data access	Source type
2	X	X (4 indicators and most supply chain steps covered)		X (lithium compounds, metal and minerals distinguished)	X (2020 projections; reserves, mining and exploration projects, commodity prices)	X	X (European Geological Survey/Statistic data compiled internally and reliant on consultancy commodity reports)
1			X (up to 2011)				
0							

Final score: **13** = high quality data

2.1.2 Data evaluation for In. Materials critical to the energy industry: An introduction

http://www.physik.uni-augsburg.de/lehrstuehle/rst/downloads/Materials_Handbook_Rev_2012.pdf

Criteria score	Geographical coverage	Data completeness	Time resolution/ frequency of update	Level of aggregation of data	Forecast data & other data	Data access	Source type
2		X (4 indicators covered)				X	
1					X (other data available: reserves, environmental impacts)		
0	X		X (2009)	X (not clearly indicated)			X (Scientific report/statistics based on a single extra-EU data source; sources of other data not clearly indicated)

Final score: **5** = medium quality data

2.1.3 Data evaluation for W: British Geological Survey – European Mineral Statistics

https://www.bgs.ac.uk/mineralsuk/statistics/europeanStatistics.html

Criteria score	Geographical coverage	Data completeness	Time resolution/ frequency of update	Level of aggregation of data	Forecast data & other data	Data access	Source type
2		X (trade data distinguishes 3 forms, but waste not separately shown; 1 indicator covered)	X (2009-2013)	X		X	X (European Official Statistic Agency/ statistic data compiled on a yearly basis, based on data that obtained from the national statistical agencies or geological surveys within the individual countries)
1	X (EU countries only)						
0					X		

Final score: **11** = high quality data

3 ANNEX C: REVIEW OF CRITICALITY ASSESSMENTS AND ORGANISATIONS INVOLVED

3.1 Overview of organisations involved in assessment of materials criticality

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Aalto University (FI)	Husgafvel_2013; Watkins_2013			Yes					
ADELPHI (DE)	Erdmann_2011b		Yes	Yes		Yes	Yes		Yes
AEA Technology plc (UK)	AEA_2010; SEPA_2011		Yes	Yes		Yes	Yes		Yes
Alpen-Adria University (AT)	Schaffartzik_2014; Purnell_2013; Roelich_2014			Yes		Yes		Yes	
American Chemistry Society (ACS, US)	AICHE_2012	No		Yes					
American Institute of Chemical Engineers (AIChE, US)	AICHE_2012	No		Yes					
American Physical Society (APS, US)	APS_2011	No				Yes			Yes
Ames Laboratory (US)	CIM_King_2013	No		Yes					
Amt für Abfall, Wasser, Energie und Luft (AWEL, CH)	Morf_2013	No		Yes			Yes		
Bachema AG (CH)	Morf_2013	No		Yes			Yes		
BIO by Deloitte (FR)	Guyonnet_2015			Yes					
British Geological Survey (BGS, UK)	BGS_2011; BGS_2012; Leal-Ayala_2015			Yes		Yes			Yes
British Petroleum (BP, UK)	BP_2014		Yes	Yes		Yes	Yes		Yes
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, DE)	Buijs_2011; Buijs_2012; ENTIRE_2013; VW_2009; Frondel_2006		Yes	Yes		Yes	Yes		Yes
Bundesministerium für Bildung und Forschung (BMBF, DE)	BMBF_2012; ENTIRE_2013			Yes					
Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW, AT)	REAP_AT_2012						Yes		
Bundesministerium für Umwelt (BMU, DE)	ENTIRE_2013			Yes			Yes		
Bundesministerium für Wirtschaft und Technologie (BMWi, DE)	BMWi_2010; Fraunhoffer_2009; ENTIRE_2013			Yes			Yes		Yes
Bundesministerium für Wissenschaft, Forschung und Wirtschaft (BMWFW, AT)	BMWFW_2014			Yes			Yes		
Bureau de Recherches Géologiques et Minières (BRGM, FR)	Beylot_2015; Guyonnet_2015			Yes					

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Bureau de Recherches Géologiques et Minières (BRGM, FR)	BRGM_2010_Te; BRGM_2011_Be; BRGM_2011_Mo; BRGM_2011_Re; BRGM_2011_Se; BRGM_2011_Ta; BRGM_2012_Graphite; BRGM_2012_Li; BRGM_2012_Sb; BRGM_2012_W; BRGM_2014_Co; BRGM_2014_PGM; BRGM_2015; Geoscience_BRGM_2012			Yes		Yes	Yes	Yes	Yes
California Institute of Technology (CALTECH, US)	Resnick_2011	No	Yes	Yes		Yes	Yes		
Centre for Strategy & Evaluation Services (CSES, UK)	CSES_2014; CSES_2014A						Yes		
Centre Interuniversitaire de Recherche sur le cycle de vie des produits, procédés et services (CIRAIG, CA)	Sonnemann_2015	No	Yes	Yes					
Centre National de la Recherche Scientifique (CNRS, FR)	Sonnemann_2015		Yes	Yes					
Centre of Studies and Technical Research of Gipuzkoa (CEIT, SP)	Iparraguirre_2014						Yes		
Centro Ricerche Fiat (CRF, IT)	CRF_2015							Yes	
Chalmers University of Technology (SE)	Cullbrand_2012		Yes	Yes			Yes		
Christian-Albrechts-Universität zu Kiel (CAU, DE)	Merrie_2014						Yes		
Christian-Albrechts-Universität zu Kiel (CAU, DE)	Beck_2015						Yes		
Clingendael International Energy Programme (NL)	Buijs_2011; Buijs_2012		Yes	Yes			Yes		
Colorado School of Mines (US)	CIM_King_2013	No		Yes					
Commissariat Général à la Stratégie et à la Prospective (CGSP, FR)	Barreau_2013			Yes			Yes		Yes
Compagnie Européenne d'Intelligence Stratégique (CEIS, FR)	BRGM_2010_Te; BRGM_2011_Be; BRGM_2011_Mo; BRGM_2011_Re; BRGM_2011_Se; BRGM_2011_Ta; BRGM_2012_Graphite; BRGM_2012_Li; BRGM_2012_Sb; BRGM_2012_W; BRGM_2014_Co; BRGM_2014_PGM						Yes		Yes
Daimler AG (DE)	Schneider_2013		Yes	Yes		Yes	Yes		
Defense National Stockpile Center (DNSC, US)	IDA_2010	No				Yes			Yes
Delft University of Technology (TUD, NL)	Peck_2015		Yes	Yes			Yes		
Delft University of Technology (TUD, NL)	Binnemans_2013						Yes		
Department Business Enterprise & Regulatory Reform (BERR, UK)	Oakdene_2008					Yes			Yes

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Department for Business Innovation and Skills (BIS, UK)	DEFRA_2012b		Yes	Yes			Yes		
Department for Environment, Food and Rural Affairs (DEFRA, UK)	DEFRA_2012; DEFRA_2012b; AEA_2010		Yes	Yes		Yes	Yes		Yes
Department of Defence (DoD, US)	DOD_2011	No				Yes			Yes
Department of Energy (DoE, US)	DOE_2010; DOE_2011	No	Yes	Yes		Yes	Yes		Yes
Department of Foreign Affairs, Government of Greenland (GL)	DK_2011						Yes		
Direction Générale de la Compétitivité, de l'Industrie et des Services (DGCIS, FR)	DCGIS_2012					Yes			
Duke University (US)	Merrie_2014	No					Yes		
ECOFYS (NL)	ECOFYS_2011; WWF_2014		Yes	Yes		Yes	Yes		Yes
Eidgenössische Technische Hochschule Zürich (ETH, CH)	Stamp_2014	No		Yes					
Eidgenössische Technische Hochschule Zürich (ETH, CH)	DeHaan_2013; Scholz_2013; Simoni_2015; Stamp_2012; Weiser_2015	No		Yes			Yes		
Elcano Royal Institute (SP)	Solera_2013		Yes	Yes			Yes		
Energy Research Partnership (ERP, UK)	Hayes-Labruto_2013						Yes		
Environment Agency (EA, UK)	EPOW_2011; SEPA_2011		Yes	Yes		Yes	Yes	Yes	Yes
Environmental Protection Agency of Canton Zurich (AWEL, CH)	Simoni_2015	No					Yes		
EU FP7 CRM_InnoNet project (EU)	CRM_InnoNet_2015; Peck_2015		Yes	Yes			Yes		
EU FP7 DESIRE project (EU)	DESIRE_2013; DESIRE_2014		Yes	Yes			Yes	Yes	
EU FP7 POLINARES project (EU)	Buijs_2011		Yes	Yes			Yes		
European Centre for Development Policy Management (ECDPM, NL)	Ramdoo_2011			Yes			Yes		
European Commission	CSES_2014; CSES_2014A						Yes		
European Commission DG ENTR	Oakdene_2013		Yes	Yes	Yes		Yes		Yes
European Environment Agency (EEA)	EEA_2011; EEA_2016; EEA_2012		Yes	Yes			Yes		
European Parliament (EP)	EP_2011; EP_STOA_2012; EP_2012; EP_2013		Yes	Yes			Yes		
European Topic Centre on Sustainable Consumption and Production (ETC/SCP)	EEA_2012			Yes			Yes		
Fachhochschule Nordwestschweiz (FHNW, CH)	Hennebel_2015	No		Yes			Yes		
FMD CARBIDE S.A.L. (SP)	Iparraguirre_2014						Yes		
Fraunhofer-Institut für System- und Innovationsforschung (ISI, DE)	Fraunhoffer_2009; Gloeser_2013; Gloeser_2015; Frondel_2006; Oakdene_2013; Buijs_2012; JRC_2013		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Free University of Amsterdam (VU, NL)	KNCV_2013			Yes			Yes		

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Freie Universität Berlin (DE)	Wubbeke_2013			Yes					
Freie Universität Berlin (DE)	Beck_2015						Yes		
General Electric (GE, US)	Duclos_2010_paper; Duclos_2010_presentation	No				Yes			
Geological Survey of Denmark and Greenland (GEUS, DK)	Machacek_2014; Machacek_2015; GEUS_2012								
Geological Survey of Finland (GTK, FI)	GTK_2010; GTK_2014; GTK_2015			Yes			Yes		
Geologische Bundesanstalt (AT)	GB_2012						Yes		
Geoscience Australia (AU)	Skirrow_2013	No	Yes			Yes		Yes	Yes
Gesellschaft für Wirtschaftliche Strukturforschung (GWS, DE)	Bruckner_2012			Yes					
Glopolis (CZ)	Glopolis_2012						Yes		
Greens/European Free Alliance Group in European Parliament	Oeko_2011			Yes			Yes		
Hague Centre for Strategic Studies (HCSS, NL)	HCSS_2010; HCSS_2010b; JRC_2011; Moss_2013		Yes	Yes		Yes			Yes
Helmholtz Institute Freiberg (HZDR, DE)	Frenzel_2015; Machacek_2015					Yes	Yes		
Helmholtz Institute Ulm (HIU, DE)	Beck_2015; Ziemann_2012; Knoeri_2013		Yes	Yes		Yes			
House of Commons (HoC, UK)	HoC_2011			Yes			Yes		Yes
HydroProc Consultants (CA)	CIM_Ferron_2013	No					Yes		
i.Con Innovation (UK)	EP_2012		Yes	Yes			Yes		
Imperial College London (UK)	UKERC_2011; UKERC_2013c		Yes	Yes				Yes	
Imperial College London (UK)	Hayes-Labruto_2013						Yes		
Industrial Technology Research Institute (TW)	Tu_2015						Yes		
Industrievereinigung (IV, AT)	IV_2012						Yes		
Inha University (KR)	Kim_2015	No				Yes		Yes	Yes
Institut der deutschen Wirtschaft Consult GmbH Köln (IW Consult, DE)	VBW_2011					Yes			Yes
Institut Européen d'Administration des Affaires (INSEAD, FR)	Ayres_2013; Peiro_2013			Yes			Yes		
Institut Francais des Relations Internationales (IFRI, FR)	IFRI_2010			Yes			Yes		
Institut für Zukunftsstudien und Technologiebewertung (IZT, DE)	Erdmann_2011; Erdmann_2011b; Fraunhoffer_2009		Yes	Yes		Yes	Yes		Yes
Institute for Defense Analyses (IDA, US)	IDA_2010	No				Yes			Yes
Institute of Materials, Minerals and Mining (IOM3, UK)	IOM3_2011						Yes		
International Copper Study Group (ICSG, PT)	Oakdene_2012			Yes					

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
International Institute for Sustainability Analysis and Strategy (IINAS, DE)	ENTIRE_2013			Yes			Yes		
International Lead and Zinc Study Group (ILZSG, PT)	Oakdene_2012			Yes					
International Nickel Study Group (INSG, PT)	Oakdene_2012			Yes					
Ionic Liquids Technologies GmbH (IOLITEC, DE)	Beck_2015						Yes		
Japan Oil, Gas and Metals National Corporation (JOGMEC, JP)	JOGMEG_2015	No			Yes	Yes			
Jean Goldschmidt International (BE)	CIM_Ferron_2013						Yes		
Joint Research Center (JRC, EC)	Moss_2013; JRC_2011; JRC_2013; JRC_2015; Mancini_2015a; Mancini_2015b; Huysman_2015		Yes	Yes		Yes			Yes
Justus-Liebig-University Giessen (DE)	Beck_2015						Yes		
Karlsruhe Institute of Technology (KIT, DE)	Ziemann_2012; Knoeri_2013		Yes	Yes		Yes			
KfW Bankengruppe (DE)	Erdmann_2011b		Yes	Yes		Yes	Yes		Yes
Korean Institute for Industrial Technology (KITECH, KR)	MIT_Bae_2010; CIM_Zampini_2013	No				Yes	Yes		Yes
Leibniz-Institut für Festkörper- und Werkstoffforschung (IFW, DE)	Moore_2015						Yes		
Leuphana University of Lüneburg (DE)	Weiser_2015; Stamp_2012			Yes			Yes		
Madariaga College of Europe Foundation (BE)	Madariaga_2011						Yes		
Materials Knowledge Transfer Network (Materials KTN, UK)	IOM3_2011						Yes		
Materials Research Society (MRS, US)	APS_2011	No				Yes			Yes
McGill University (CA)	CIM_Zampini_2013	No					Yes		
Mendel University (CZ)	Chakhmouradian_2015		Yes	Yes			Yes		
Metal Economics Research Institute (MERI, JP)	Okada_2011	No		Yes		Yes	Yes		Yes
Ministry for Resources and Energy (AU)	Skirrow_2013	No	Yes			Yes		Yes	Yes
Ministry of Economic Affairs (NL)	TNO_2014			Yes	Yes	Yes	Yes	Yes	Yes
Ministry of Economy (RO)	RO_2012			Yes			Yes		
Ministry of Employment and Economy (FI)	GTK_2010			Yes			Yes		
Ministry of Environment, Energy and Climate Change (HE)	MEECC			Yes					
Ministry of Foreign Affairs (DK)	DK_2011						Yes		
Ministry of Foreign Affairs (FO)	DK_2011						Yes		
Ministry of Foreign Affairs (NL)	BuZa_2013; NL_2011			Yes			Yes	Yes	
Monash University (AU)	Mason_2011	No				Yes			

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Montanuniversität Leoben (AT)	Marinescu_2013						Yes		
National Center for Scientific Research Demokritos (HE)	EP_2012		Yes	Yes			Yes		
National Cheng-Kung University (TW)	Tu_2015						Yes		
National Institute of Advanced Industrial Science and Technology (AIST, JP)	Watanabe_2011	No							Yes
National Institute of Advanced Industrial Science and Technology (AIST, JP)	Hatayama_2015; Seo_2013	No		Yes		Yes	Yes		Yes
National Research Council (NRC, US)	NRC_2008	No				Yes			Yes
Natural Environment Research Council (NERC, UK)	NERC						Yes		
Natural Resources GP (HE)	Nicoletopoulos_2014			Yes			Yes		
Netherlands Environmental Assessment Agency (PBL, NL)	PBL_2011			Yes		Yes	Yes		Yes
Netherlands Organisation for Applied Scientific Research (TNO, NL)	HCSS_2010; TNO_2014; HCSS_2010b			Yes	Yes	Yes		Yes	Yes
Neue Sachlichkeit (CH)	Scholz_2013	No		Yes			Yes		
Northeastern University (US)	Harper_2015b	No	Yes	Yes			Yes		Yes
Northern Ireland Environment Agency (UK)	SEPA_2011		Yes			Yes	Yes		Yes
Oakdene Hollins (UK)	Moss_2013; EPOW_2011; Oakdene_2008; Oakdene_2012; Oakdene_2013; JRC_2011; JRC_2013		Yes	Yes	Yes	Yes		Yes	Yes
Oeko-Institut e.V. (DE)	Oeko_2009; Oeko_2011; Binnemans_2013			Yes		Yes			Yes
Office parlementaire d'évaluation des choix scientifiques et technologiques (FR)	Hetzel_2014			Yes					
Organisation for Economic Co-operation and Development (OECD, UN)	OECD_2011	No				Yes			
Pacific Northwest Laboratory (US)	Smith_1984	No				Yes			
Pennsylvania State University (US)	Nieto_2013	No				Yes			
PLATEFORME [avniR]-cd2e (FR)	Sonnemann_2015		Yes	Yes					
Polish Academy of Sciences (PL)	Niec_2014						Yes		
Politecnico di Milano (IT)	Cucchiella_2015						Yes		
Polytechnic University of Tomsk (R)	Kim_2015					Yes		Yes	Yes
PricewaterhouseCoopers (PwC, US)	PwC_2011	No					Yes		
Ramboll Management Consulting (DK)	EP_2012		Yes	Yes			Yes		
Renault (FR)	Geoscience_Renault_2012					Yes			
Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI, DE)	Frondel_2006					Yes			Yes
Rochester Institute of Technology (US)	Bustamante_2014; Goe_2014	No		Yes		Yes		Yes	Yes
RockTron International Limited (UK)	Blissett_2014			Yes			Yes		

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Rolls-Royce (UK)	Loyd_2012		Yes	Yes			Yes		
Royal Institute of Technology (KTH, SE)	Asif_2015			Yes					
Royal Netherlands Chemical Society (KNCV, NL)	KNCV_2013			Yes			Yes		
Samsung Engineering Co. (KR)	Kim_2015	No				Yes		Yes	Yes
Santa Catarina State University (UDESC, BR)	Huysman_2015						Yes		
School of Engineering, San Sebastián (TECNUN, SP)	Iparraguirre_2014						Yes		
Science and Technology Committee (STC, UK)	HoC_2011			Yes			Yes		Yes
Scotland & Northern Ireland Forum for Environmental Research (SNIFFER, UK)	SEPA_2011		Yes			Yes	Yes		Yes
Scottish Environment Protection Agency (SEPA, UK)	SEPA_2011		Yes			Yes	Yes		Yes
Shanghai Normal University (CN)	Tu_2015						Yes		
SOLVAY Group (FR)	Guyonnet_2015			Yes					
Stanford University (US)	Vesborg_2012	No		Yes					
Statistics Netherlands (CBS, NL)	CBL_2011			Yes		Yes		Yes	
Stellenbosch Institute for Advanced Study (STIAS, SA)	Graedel_2015b; Nassar_2015b	No		Yes			Yes		
Stockholm Environment Institute (SEI, SE)	SEI_2012			Yes			Yes		Yes
Sustainable Europe Research Institute (SERI, AT)	Bruckner_2012			Yes					
Swiss Academy of Engineering Sciences (SATW, CH)	SATW_2010	No				Yes	Yes		
Swiss Federal Laboratories for Materials Science and Technology (EMPA, CH)	Stamp_2012; Weiser_2015	No		Yes			Yes		
Swiss Federal Laboratories for Materials Science and Technology (EMPA, CH)	Stamp_2014; Knoeri_2013	No	Yes	Yes		Yes	Yes		
Technical University of Denmark (DTU, DK)	Vesborg_2012			Yes					
Technische Universität Bergakademie Freiberg (DE)	Frenzel_2015					Yes	Yes		
Technische Universität Berlin (DE)	Schneider_2013		Yes	Yes		Yes	Yes		
Technische Universität Clausthal (DE)	ENTIRE_2013; Gloeser_2013; Gloeser_2015		Yes	Yes			Yes	Yes	
Technische Universität Wien (AT)	Zuser_2011			Yes					
Thales (FR)	Thales_2013						Yes		
Transatlantic Academy (US)	TRANSLATLANTIC_2011	No					Yes		
UK Energy Research Centre (UKERC, UK)	UKERC_2013; UKERC_2014; UKERC_2011; UKERC_2013c		Yes	Yes				Yes	

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
United Nations Conference on Trade and Development (UNCTAD, UN)	UNCTAD_2014	No					Yes		
United Nations Environment Programme (UNEP, UN)	Oeko_2009	No				Yes			Yes
Universität Augsburg (DE)	Beck_2015; Achzet_2013; BP_2014; Gleich_2013; Mayer_2015; VBW_2011		Yes	Yes		Yes			Yes
Universität Duisburg-Essen (DE)	Beck_2015						Yes		
Universität für Bodenkultur Wien (BOKU, AT)	Gsodam_2014					Yes	Yes		
Universität Graz (AT)	Gsodam_2014					Yes	Yes		
Université de Bordeaux (FR)	Sonnemann_2015		Yes	Yes					
Université de Technologie de Troyes (FR)	Kim_2015					Yes		Yes	Yes
Université Toulouse III - Paul Sabatier (FR)	Guyonnet_2015			Yes					
University autonomous de Barcelona (SP)	Peiro_2013			Yes			Yes		
University of Birmingham (UK)	Blissett_2014; Binnemans_2013			Yes			Yes		
University of Bremen (DE)	Zimmerman_2013						Yes		
University of Brighton (UK)	Chakhmouradian_2015		Yes	Yes			Yes		
University of Bucharest (RO)	Marinescu_2013						Yes		
University of California (US)	Hennebel_2015	No		Yes			Yes		
University of Cambridge (UK)	Leal-Ayala_2015						Yes		
University of Copenhagen (DK)	Machacek_2014; Machacek_2015						Yes		
University of Cranfield (UK)	Powell-Turner_2015						Yes		
University of Exeter (UK)	Wall_2012						Yes		
University of Ghent (BE)	Hennebel_2015			Yes			Yes		
University of Ghent (BE)	Huysman_2015						Yes		
University of Gothenburg (SE)	Wakolbinger_2014						Yes		
University of Hull (UK)	Gomes_2015			Yes					
University of L'Aquila (IT)	Cucchiella_2015						Yes		
University of Leeds (UK)	Gomes_2015; SEI_2012; Knoeri_2013; Purnell_2013; Roelich_2012; Roelich_2014		Yes	Yes		Yes			Yes
University of Leuven (BE)	Binnemans_2013						Yes		
University of Lund (SE)	Machacek_2015						Yes		
University of Manitoba (CA)	Chakhmouradian_2015	No	Yes	Yes			Yes		
University of Massachusetts (US)	Wakolbinger_2014	No					Yes		
University of Milan (IT)	Baldi_2014		Yes						
University of Miskolc (HU)	Földessy_2014						Yes		
University of Palermo (IT)	Asif_2015			Yes					
University of Queensland (AU)	Golev_2014	No							
University of Salento (IT)	Massari_2013			Yes			Yes		
University of Sheffield (UK)	Cucchiella_2015						Yes		

Organisations	Short reference	EU only?	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
University of Southampton (UK)	Ongondo_2015						Yes		
University of Southern Denmark (DK)	Habib_2014; Habib_2015; Machacek_2015		Yes	Yes		Yes	Yes		
University of Stockholm (SE)	Merrie_2014						Yes		
University of Surrey (UK)	Loyd_2012		Yes	Yes			Yes		
University of Technology, Kaunas (LT)	Knašytė_2012				Yes				Yes
University of Technology, Sydney (AU)	Mason_2011	No				Yes			
University of Tromsø (NO)	Merrie_2014						Yes		
University of Utrecht (NL)	Merrie_2014						Yes		
University of Wageningen (NL)	Hennebel_2015; Dijk_2015			Yes					
University of Warsaw (PL)	Niec_2014						Yes		
University of York (CA)	Wakolbinger_2014	No					Yes		
Valero Research Centre for Energy Resources and Consumption (CIRCE, SP)	Calvo_2016							Yes	
Vereinigung der Bayerischen Wirtschaft (VBW, DE)	VBW_2011					Yes			Yes
Volkswagen AG (VW, DE)	VW_2009					Yes			
Wirtschaftsuniversität Wien (WU, AT)	Wakolbinger_2014						Yes		
World Foresight Forum Foundation (WFF, NL)	HCSS_2010b								
World Wide Fund for Nature (WWF, CH)	WWF_2014	No	Yes	Yes		Yes	Yes		Yes
Wuppertal Institut für Klima, Umwelt, Energie GmbH (DE)	Viebahn_2015							Yes	
Yale University (US)	Elshkaki_2015; Graedel_2012; Graedel_2015; Graedel_2015b; Graedel_2015c; Harper_2015; Harper_2015b; Nassar_2012; Nassar_2015; Nassar_2015b; Nassar_2015c; Nuss_2014; Panousi_2015; Erdmann_2011	No	Yes	Yes		Yes			Yes
Zentrum für nachhaltige Abfall-und Ressourcennutzung (ZAR, CH)	Morf_2013	No		Yes			Yes		

3.2 Organisations developing their own methodologies

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
ADELPHI (DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC methodology	See Institute for Futures Studies and Technology Assessment (Erdmann_2011b) for further details.
AEA Technology plc (UK)		To assess future resource risks faced by UK business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	AEA_2010: The two dimensions of criticality are consumption/production and scarcity/availability, based on the following indicators: • Availability of alternatives • Supply distribution • Supply domination • Extent of Geopolitical Influences • Press Coverage • Price Fluctuations See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for follow-up and further details.
Alpen-Adria University (AT)		To monitor potential disruption in supply of critical materials which could endanger a transition to low-carbon infrastructure	References EC methodology	See university of Leeds (Roelich_2014) for further details.
American Physical Society (APS, US)	No	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of potential action by the United States to insure their availability		From Peck_2015: The term 'energy-critical element' is used to describe a class of chemical elements that currently appears critical to one or more new energy-related technologies. More specifically: 1. Elements that have not been widely extracted, traded, or utilised in the past 2. Elements that could significantly inhibit large-scale deployment of the new energy-related technologies
British Geological Survey (BGS, UK)		To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	See BGS_2011 for orginal methodology. BGS_2012: An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on seven criteria scored between 1 and 3. • Scarcity • Production concentration • Reserve distribution • Recycling Rate • Substitutability • Governance (top producing nation) • Governance (top reserve-hosting nation)
British Petroleum (BP, UK)		To improve understanding of the risk to the sustainability of each existing energy pathways induced by restricted supply of materials through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	BP_2014: Criticality is defined as the degree to which a material is necessary as a contributor to an energy pathway, based on: • Reserves, • Trades, • Ecological impact, • Processing, • Substitutability, • Recyclability

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, DE)		To assess materials critical to the German economy through the development of a methodology	References EC methodology	See Rheinisch-Westfälisches Institut für Wirtschaftsforschung (Frondel_2006) for further details. See Volkswagen (VW_2009) for further details.
Bureau de Recherches Géologiques et Minières (BRGM, FR)		To assess materials critical to France through the development and use of a criticality methodology	References EC methodology	BRGM_2015: Strategic importance for the French industry vs. risk of supply based on the following indicators: 1 - Demand and consumption 2 - Production and resources 3 - Substitutability 4 - Recycling 5 - Price 6 - Restrictions to international trade, Reglementations 7 - French production and resources 8 - French industry in the sector 9 - French trade and consumption
California Institute of Technology (CALTECH, US)	No	To assess the criticality of materials for sustainable energy applications through the development of a methodology	References EC methodology	Resnick_2011: Critical materials are determined in terms of importance to the clean energy economy and risk of supply disruption
Daimler AG (DE)		To assess materials through the development of a criticality methodology and its use for selected materials	References EC methodology	Schneider_2013: Based on a life cycle perspective, the supply risk associated with resource use can be assessed, and bottlenecks within the supply chain can be identified. This analyses relies on the following indicators: • Reserves • Recycling • Concentration of one activity • Economic stability • Demand growth • Trade barriers • Companion metal fraction
Defense National Stockpile Center (DNSC, US)	No	To define a list of critical materials through the development and use of a criticality methodology, supporting US defence sector		See Institute for Defense Analyses (IDA_2010) for further details.
Department Business Enterprise & Regulatory Reform (BERR, UK)		To assess materials to ensure UK's military and economic sufficiency through the development of a criticality methodology and its use in the definition of a list of critical materials		Oakdene_2008: Based on Yale methodology • 'Material risk' criteria: - global consumption levels (A) - lack of substitutability (B) - global warming potential (C) - total material requirement (D) • 'Supply risk' criteria: - scarcity (E) - monopoly supply (F) - political instability in key supplying regions (G) - vulnerability to the effects of climate change in keysupplying regions (H)

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
Department for Environment, Food and Rural Affairs (DEFRA, UK)		To detail how the UK Government recognises private sector concerns about the availability of some raw materials, provides a framework for business action to address resource risks, and sets out high level actions to build on the developing partnership between Government and businesses to address resource concerns	References EC methodology	See AEA Technology plc (AEA_2010) for further details.
Department of Defence (DoD, US)	No	To assess U.S. vulnerabilities with respect to strategic and critical materials through the development of a criticality methodology and its use in the definition of a list of critical materials		DOD_2011: The material shortfalls are estimated via a three step quantitative methodology: 1. Projection of demand on the economy for manufactured goods and services related to the military, industrial, and essential civilian sectors during the particular scenario. 2. Estimation of the quantities of strategic and critical materials needed to produce these goods and services. 3. Estimation of the amounts of domestic and reliable foreign supplies of strategic and critical materials available in the scenario, and compares them, on a time-phased basis, to the material demands computed in the second step. Any projected supply gaps (shortfalls) are identified. These shortfalls can become candidate goals for NDS inventory levels or targets to address with other mitigation strategies.
Department of Energy (DoE, US)	No	To assess the role of rare earth metals and other materials in the clean energy economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	See DOE_2010 for the original methodology. DOE_2011: In analogy to the NRC_2008 methodology, the two-dimensional criticality ratings consider importance to clean energy vs. supply risk • Importance to clean energy encompasses: - Clean Energy Demand - Substitutability Limitations • The overall supply risk for each material is based on five categories of risk for the short and medium term: - Basic Availability - Competing Technology Demand - Political, Regulatory and Social Factors - Co-dependence on other Markets - Producer Diversity
Direction Générale de la Compétitivité, de l'Industrie et des Services (DGCIS, FR)		To assess companies' vulnerability with respect to CRM through a specific method/software. For companies with a high level of vulnerability towards CRM, a potential substitution path may be proposed		DCGIS_2012: Vulnerability of a company vs. risk of supply • Risk of supply relies on the following indicators: - Political stability of producing countries (WGI) - Level of production concentration (HHI) Concentration of producing countries Concentration of producing companies - Free trade limitations - Fraction of co-production (level of risk related to the one of the main metal) - Price volatility - French recycling capacity at End Of Life Level of development of recycling sector in France Rate of recycling Fraction of consumption from recycling

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
				• Vulnerability of a company relies on the following indicators: - Economic importance for the company - Capacity to handle price increase - Importance for company strategy - Characteristics of substitutes - Capacity of company to innovate - Understanding of supply-chain - Constraints, among others from regulations
ECOFYS (NL)		To assess demand and supply of rare metals for the renewable energy sector	References EC methodology	See World Wide Fund for Nature (WWF_2014) for further details.
Environment Agency (EA, UK)		To turn waste into resources thereby supporting UK economy	References EC methodology	See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for further details.
Fraunhofer-Institut für System- und Innovationsforschung (ISI, DE)		To assess raw materials for emerging technologies by the development of a criticality methodology and its use in the definition of a list of critical materials	Uses EC methodology	See Rheinisch-Westfälisches Institut für Wirtschaftsforschung (Frondel_2006) for further details. See Joint Research Center (JRC_2013) for follow-up.
General Electric (GE, US)	No	To assess critical materials to GE through the development of a methodology and its use for selected materials		Duclos_2010_paper: The criticality diagram is constructed by plotting the "Impact of an Element Restriction on GE" versus the "Supply and Price Risk" based on the following indicators: - GE's percent of world supply - Impact on GE's revenue - GE's ability to substitute - Ability to pass through cost increases - Abundance in Earth's crust - Sourcing and geopolitical risk - Co-production risk - Demand risk - Historic price volatility - Market substitutability
Geoscience Australia (AU)	No	To examine critical commodities from an Australian perspective and presents comprehensive technical (geological) information on Australia's resources and resource potential for these		The assessments of resource potential are subjective judgements based on: • Level of criticality; • Australia's resources and potential for new discoveries; • Market size; and • Growth outlook.
Hague Centre for Strategic Studies (HCSS, NL)		To discuss parameters impacting scarcity of minerals and to review strategic mineral policies	References EC methodology	HCSS_2010: Three criteria were used to assess which minerals may become scarce: First, the importance of these elements for the industrial sector, with special emphasis on high-tech industries. Second, the sample included elements for which few substitutes are known, as society is particularly vulnerable to shortages in these minerals. Third, the sample included elements which are crucial to emerging technologies, with particular emphasis on alternative energy and other 'green technologies'. See JRC_2011 for further details.

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
Helmholtz Institute Freiberg (HZDR, DE)		To investigate the supply potential of elements		Frenzel_2015: Statistical and deterministic models are introduced to quantify both the variability in by-product concentrations in the relevant raw materials, as well as the effects of this variability on achievable recoveries.
Helmholtz Institute Ulm (HIU, DE)		To assess materials through the development of a criticality methodology	References EC methodology	See University of Leeds (Knoeri_2013) for further details.
Inha University (KR)	No	To assess the materials consumption and requirement in wind energy system in the EU 27		The current consumption and future requirement of critical and precious materials were calculated and estimated using the wind power production dataset from ecoinvent and data from National Renewable Energy Action Plan (NREAP)
Institut der deutschen Wirtschaft Consult GmbH Köln (IW Consult, DE)		To raise awareness of businesses and governments through the development of a criticality methodology and its use in the definition of a list of critical materials		See Vereinigung der Bayerischen Wirtschaft (VBW_2011) for further details.
Institut für Zukunftsstudien und Technologiebewertung (IZT, DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC methodology	Erdmann_2011b: The two dimensions of criticality are vulnerability vs. risk of supply: • Vulnerability relies on 6 indicators: - Volume Relevance Germany's share of world consumption Change in the share of Germany in global consumption Change of German imports - Strategic relevance Sensitivity of the value chain in Germany Global demand momentum by technologies of the future Substitutability • Risk of supply relies on 7 indicators: - Country Risk Country risk for the imports of Germany Country risk for the global production Countries concentration of global reserves - Market Risk Corporate concentration of global production Ratio of global reserves to global production - Structural risk Share of the global primary and secondary production Recyclability
Institute for Defense Analyses (IDA, US)	No	To define a list of critical materials through the development and use of a criticality methodology, supporting US defence sector		IDA_2010: The material shortfalls are estimated via a three step quantitative methodology: 1. Projection of demand on the economy for manufactured goods and services related to the military, industrial, and essential civilian sectors during the particular scenario. 2. Estimation of the quantities of strategic and critical materials needed to produce these goods and services. 3. Estimation of the amounts of domestic and reliable foreign supplies of strategic and critical materials available in the scenario, and compares them, on a time-phased basis, to the material demands computed in the second step. Any projected supply gaps (shortfalls) are identified. These shortfalls can become candidate goals for NDS inventory levels or targets to address with other mitigation strategies.

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
Japan Oil, Gas and Metals National Corporation (JOGMEC, JP)	No	To assess the degree of importance of mineral commodities in Japan in order to contribute to secure stability of mineral resources, based on the EC methodology	Uses EC methodology	Method based on the European Commission's methodology of 2010: • Economic Importance - End uses of metals - Gross value added (GVA) - Price - Quantity of domestic demand - Quantity of world demand • Supply Risk - Import partner countries - Producing countries - Uneven distribution of reserve - Substitutability - Recycle - Main product/by-product
Joint Research Center (JRC, EC)		To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system and to assess the sustainability of the production and supply of raw materials and primary energy carriers through the development of methodologies	References EC methodology	See JRC_2011 for original methodology. JRC_2013: The approach focuses on four criteria to evaluate risks for future supply chain bottlenecks for individual metals: • Market factors - Limitations to expanding supply capacity - Likelihood of rapid global demand growth. • Geopolitical factors - Cross-country concentration of supply - Political risk related to major supplying countries JRC_2015: 10 sustainability concerns are grouped into the following areas: - Environmental - Economic - Social/societal - Technical/technological
Karlsruhe Institute of Technology (KIT, DE)		To assess materials through the development of a criticality methodology	References EC methodology	See University of Leeds (Knoeri_2013) for further details.
KfW Bankengruppe (DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC methodology	See Institute for Futures Studies and Technology Assessment (Erdmann_2011b) for further details.
Korean Institute for Industrial Technology (KITECH, KR)	No	To ensure Korea materials supply security		MIT_Bae_2010: Korea "rare" elements are subject to instability in supply and price fluctuations and selected based on rarity, instability, and concentration of supply and demand. The rarity is normalized to steel.
Materials Research Society (MRS, US)	No	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of		See American Physical Society (APS_2011) for further details.

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
		potential action by the United States to insure their availability		
Metal Economics Research Institute (MERI, JP)	No	To serve as reference for those who supply metal resources or those who utilise metal resources, though the development and use of a criticality methodology	References EC methodology	Okada_2011: Assessment of critical metals based on supply risk and on metal price trends • Supply risk: - Assessment based on Herfindahl-Hirschman Index (HHI) - Assessment employing Worldwide Governance Indicator (WGI) - Ores and Metals (Supply Chain): ores (extraction) and unprocessed metal (smelting): these will be examined employing an HHI. • Critical Risk as discerned from Price Trends - Medium and long term prices - 2010 monthly average price
Ministry for Resources and Energy (AU)	No	To examine critical commodities from an Australian perspective and presents comprehensive technical (geological) information on Australia's resources and resource potential for these		The assessments of resource potential are subjective judgements based on: • Level of criticality; • Australia's resources and potential for new discoveries; • Market size; and • Growth outlook.
Ministry of Economic Affairs (NL)		To assess the vulnerability of the Dutch economy and provide guidance to stakeholders regarding raw materials through the development of a qualitative and quantitative criticality method and its use	Uses EC methodology	See Netherlands Organisation for Applied Scientific Research (TNO_2014) for further details
Monash University (AU)	No	To discuss factors impacting criticality, in view of assessing the impact of production peak on the Australia production of minerals and its impacts on the Australian economy		See University of Technology (Mason_2011) for further details.
National Institute of Advanced Industrial Science and Technology (AIST, JP)	No	To define a list of critical metals for JP based on the definition and use of a criticality methodology	References EC methodology	Hatayama_2015: Criticality assessment of metals has been developed to analyse a country's supply risk and vulnerability to supply restriction. The evaluation framework developed in this study included 13 criticality components within five risk categories: supply risk, price risk, demand risk, recycling restriction, and potential risk. • Supply risk - Depletion time - Concentration of reserves - Concentration of ore production - Concentration of import trading partners • Price risk - Price change - Price variation • Demand risk - Mine production change - Domestic demand growth - Domestic demand growth for specific uses • Recycling restriction - Stockpiles - Recyclability

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
				• Potential risk - Possibility of usage restrictions
National Research Council (NRC, US)	No	To define a list of critical materials to the US economy through the development and use of a criticality methodology		NRC_2008: Impact of Supply Restriction vs. Supply Risk, with indicators such as • Geologic Availability • Technical Availability • Environmental and Social Availability • Political Availability • Economic Availability
Netherlands Environmental Assessment Agency (PBL, NL)		To review policy context dealing with resources scarcities	References EC methodology	PBL_2011: Three dimensions of scarcity are distinguished: • Physical, for example: - Depletion of reserves - Insufficient renewable production / stocks • Economic, for example: - Malfunctioning markets (infrastructure and communication) - Harmonisation of production capacity in relation to demand • Political, for example: - Trade barriers / export disruptions - Conflicts.
Netherlands Organisation for Applied Scientific Research (TNO, NL)		To assess the vulnerability of the Dutch economy and provide guidance to stakeholders regarding raw materials through the development of a qualitative and quantitative criticality method and its use	Uses EC methodology	See Hague Centre for Strategic Studies (HCSS_2010) for further details. TNO_2014: Assessment of the importance of the raw materials for the Dutch economy vs. supply risk + vulnerability on the basis of price volatility and mineral reserves. • Supply - Reserve/production - Concentration of materials (measured by HHI) of originating countries - Stability and governance (given by WGI) of source countries - Substitution options on product level - Sufficient Quality of sourcing materials - Future supply/demand ratio - Insight in complete supply chain? • Impact on profitability - Ability to pass through cost increases - Percent of revenue impacted - Impact of price volatility of (raw) material at product and/or company level • External effects - EPI and HDI of sourcing countries - Impeding policy regulations present (for demand or supply)
Northern Ireland Environment Agency (UK)		To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials		See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for further details.
Oakdene Hollins (UK)		To define a list of critical materials for the EU through the use of the EC methodology	Uses EC methodology	See Oakdene_2008 for original method. See Joint Research Center (JRC_2013) for further details.
Oeko-Institut e.V. (DE)		To assess the impact of specific materials on future sustainable technologies (FST), such as renewable	References EC methodology	Oeko_2009: Iterative process: • General prioritization (1st step): Critical metals are defined by: - High demand growth

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
		energies and energy efficient technologies, through the development and use of a criticality methodology		- High supply risks - Recycling restrictions • Focused prioritization regarding demand (2nd step): - Demand Growth • Focused prioritization regarding supply (3rd step): - Regional concentration of mining - Physical scarcities - Temporary scarcity - Structural or technical scarcity • Focused prioritization regarding recycling (4th step): - High scale of dissipative applications - Physical/chemical limitations for recycling - Lack of suitable recycling technologies and/or infrastructures - Lack of prices incentives for recycling
Organisation for Economic Co-operation and Development (OECD, UN)	No	To assess critical materials for mobile devices through the development and use of a methodology		OECD_2011: The report identifies four methodologies: (1) substance flow analysis; (2) life cycle assessment; (3) eco-efficiency and (4) a new proposed framework for incorporated social aspects.
Pacific Northwest Laboratory (US)	No	To identify potential commercialization barriers to new PV technologies by the identification of material shortages through a criticality assessment program		Smith_1984: The Critical Materials Assessment Program (CMAP) is an interactive computerized methodology that can assist in identifying potential material supply constraints due to the large-scale deployment of new technologies. Step 1: identification of materials requirements Step 2: identification of the cell production process Step 3: specification of the deployment scenarios Step 4: computation of the annual materials requirements Step 5: analysis of the materials production processes Step 6: characterization of the materials industry Step 7: assessment of the technology's impact Step 8: analysis of the results Step 9: study of the alternative options or mitigating strategies
Pennsylvania State University (US)	No	To assess criticality for REE in petroleum refining materials through the development and use of a criticality methodology		Nieto_2013: Identification of five key supply risk factors (KSRFs): • Producer diversity • Resources risk factor • Demand from alternative applications • International trade environment • Environmental regulations
Polytechnic University of Tomsk (R)		To assess the materials consumption and requirement in wind energy system in the EU 27		The current consumption and future requirement of critical and precious materials were calculated and estimated using the wind power production dataset from ecoinvent and data from National Renewable Energy Action Plan (NREAP)
Renault (FR)		To assess materials through the development of a criticality methodology		Geoscience_Renault_2012: Impact of supply restriction on Renault vs. risks on prices or supply (based on Yale methodology): • Risk factors influencing prices and/or supply: – Level of concentration of producers, and a governance indicator for economic and geopolitical stability of producing countries; – Environmental Performance Index; – Share of recycled material in consumption;

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
				– Availability of coproducts; – Price volatility (over the last 3 years). • Factors having an impact of the activity of the constructor: – Technical importance of materials in cars; – Indicator on purchase price; – Substitutability; – Future price.
Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI, DE)		To assess materials critical to the German economy through the development of a methodology		Frondel_2006: Three criteria determine if a raw material is currently classified as critical from a German perspective: (1) value of net imports (2) the concentration of production , which is measured using the Herfindahl index (3) political and economic risks of producing countries which is quantified using a range of relevant indicators of the world
Rochester Institute of Technology (US)	No	To identify critical materials for photovoltaics in the US trough the development of a criticality methodology and its use	References EC methodology	Goe_2014: The selection of the indicators listed below was motivated by broad applicability to the PV materials of interest and data availability. • Supply - Net import reliance - Herfindahl–Hirshmann index of primary material and ore producers - Recycling rate - Ratio of production to reserves • Environmental - CERCLA points - Primary embodied energy - Energy savings • Economic - Primary material price - Domestic consumption - Economic value by sector
Samsung Engineering Co. (KR)	No	To assess the materials consumption and requirement in wind energy system in the EU 27		The current consumption and future requirement of critical and precious materials were calculated and estimated using the wind power production dataset from ecoinvent and data from National Renewable Energy Action Plan (NREAP)
Scotland & Northern Ireland Forum for Environmental Research (SNIFFER, UK)		To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials		SEPA_2011: Production/consumption vs. availability/scarcity. Criteria considered were: • Combined consumption/production and scarcity/availability • Availability of alternatives • Supply distribution • Supply domination • Extent of geopolitical Influences • Press coverage • Price fluctuation
Scottish Environment Protection Agency (SEPA, UK)		To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials		See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for further details.
Statistics Netherlands (CBS, NL)		To assess the impact of critical materials on the Dutch economy through the development of a	References EC methodology	CBL_2011: The method follows a three-step approach: 1. classification of product groups based on the most detailed categorization used within the system of national accounts.

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
		criticality methodology and its use in the definition of a list of critical materials		2. estimation of the amount of critical materials required to produce each product group. 3. determination to which extent the intermediate use of products by industries consists of critical materials.
Swiss Academy of Engineering Sciences (SATW, CH)	No	To assess materials through the development of a criticality methodology and its use for selected materials		SATW_2010: The following factors contribute to the criticality of materials: • Geologic • Geopolitics • Technologic • Economic • Social • Ecologic
Swiss Federal Laboratories for Materials Science and Technology (EMPA, CH)	No	To assess the impact of metal demand on energy scenarios	References EC methodology	See University of Leeds (Knoeri_2013) for further details.
Technische Universität Bergakademie Freiberg (DE)		To develop a general method for the assessment of the supply potential of elements		Statistical and deterministic models are introduced to quantify both the variability in by-product concentrations in the relevant raw materials, as well as the effects of this variability on achievable recoveries.
Technische Universität Berlin (DE)		To assess materials through the development of a criticality methodology and its use for selected materials	References EC methodology	Schneider_2013: Based on a life cycle perspective, the supply risk associated with resource use can be assessed, and bottlenecks within the supply chain can be identified. This analyses relies on the following indicators: • Reserves • Recycling • Concentration of one activity • Economic stability • Demand growth • Trade barriers • Companion metal fraction
United Nations Environment Programme (UNEP, UN)	No	To assess future sustainable technologies (FST), such as renewable energies and energy efficient technologies, which will make use of specific materials, through the development and use of a criticality methodology		See Oeko (Oeko_2009) for further details.
Universität Augsburg (DE)		To assess materials through the development of a criticality methodology and its use for selected materials	References EC methodology	Gleich_2013: Methodology relies on: • Resource specific factors: - Country concentration, - Producer concentration, - World mine production, - Apparent consumption, - Secondary production, - Stocks. • And economic and demographic factors: - GDP,

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
				- World population, - Inflation, - Interest rate. Mayer_2015: Assessing supply risks of minerals criticality, based on Gleich_2013, in form of future price development and volatility.
Universität für Bodenkultur Wien (BOKU, AT)		To carry out a material flow analysis of silver in Austria for the period 2012		The MFA framework consists of a total offour main processes, each of which can be subdivided into various sub-processes. The four main processes in our system were: (1) The production process: Crude silver ore is extracted, separatedfrom its parent materials, and processed into refined silver. (2) The fabrication and manufacture process: Silver semi-productsare produced from refined silver. The silver semi-products arethen used in the manufacture process to make the finishedsilver products. Scrap is sent back to fabrication or to the pro-duction process for recycling. (3) The use process: In this process, silver is available either in theform of finished silver and silver alloy products or in the formof components of finished products. (4) The waste management process: The associated waste streamswithin this process are municipal solid waste, waste fromelectrical and electronic equipment, industrial waste, and haz-ardous waste. The discarded silver is recycled back into refinedsilver, treated thermally in an incineration plant or stored in landfills.
Universität Graz (AT)		To carry out a material flow analysis of silver in Austria for the period 2012		The MFA framework consists of a total offour main processes, each of which can be subdivided into various sub-processes. The four main processes in our system were: (1) The production process: Crude silver ore is extracted, separatedfrom its parent materials, and processed into refined silver. (2) The fabrication and manufacture process: Silver semi-productsare produced from refined silver. The silver semi-products arethen used in the manufacture process to make the finishedsilver products. Scrap is sent back to fabrication or to the pro-duction process for recycling. (3) The use process: In this process, silver is available either in theform of finished silver and silver alloy products or in the formof components of finished products. (4) The waste management process: The associated waste streamswithin this process are municipal solid waste, waste fromelectrical and electronic equipment, industrial waste, and haz-ardous waste. The discarded silver is recycled back into refinedsilver, treated thermally in an incineration plant or stored in landfills.
Université de Technologie de Troyes (FR)		To assess the materials consumption and requirement in wind energy system in the EU 27		The current consumption and future requirement of critical and precious materials were calculated and estimated using the wind power production dataset from ecoinvent and data from National Renewable Energy Action Plan (NREAP)
University of Leeds (UK)		To monitor potential disruption in supply of critical materials which could endanger such a transition to low-carbon infrastructure	References EC methodology	Knoeri_2013: Dynamic interactions between different possible demand and supply configurations Roelich_2014: Two dimensions of risk are Supply disruption potential (P) vs. Exposure to disruption (E). „„• Supply disruption potential (P), is defined by the following 4 indicators: - Production-requirements imbalance - Companion fraction - Access - Environmental constraints

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
				„„• Exposure to disruption (E), is defined by the following 2 indicators: - Goal sensitivity - Price sensitivity
University of Southern Denmark (DK)		To improve criticality assessment studies by taking a dynamic and technology specific approach	References EC methodology	Habib_2015: Adresses two concerns not considered by existing methods: A need for dynamic perspective of the supply risk with respect to both the geological and geopolitical aspects; The ability of methods to properly account for the importance of the supply risk of a given resource or the vulnerability of the studied system or technology to a disruption of the supply of the resource in question.
University of Technology, Sydney (AU)	No	To discuss factors impacting criticality, in view of assessing the impact of production peak on the Australia production of minerals and its impacts on the Australian economy		Mason_2011: Evaluation of the impacts of changing patterns of mineral production through three criteria: 1. availability of a resource; 2. society's addiction to the resource; 3. and the possibility of finding alternatives
Vereinigung der Bayerischen Wirtschaft (VBW, DE)		To raise awareness of businesses and governments through the development of a criticality methodology and its use in the definition of a list of critical materials		VBW_2011: The Commodity Risk Index consists of eight criteria, which are grouped into quantitative and qualitative indicators: „„• Quantitative indicators: - Reserves-to-production ratio - Political stability in producing countries - Concentration of 3 main producing countries - Concentration of 3 main producing companies - Price risk „„• Qualitative indicators: - Importance for future technologies - Risk of strategic deployment - Substitutability
Volkswagen AG (VW, DE)		To assess materials supply risk through the development of a criticality methodology and its use for selected materials		VW_2009: The method is based on a combined evaluation of past and future supply and demand trends. Indicators for market assessment are: 1. Current supply and demand 2. Production costs 3. Geo strategic risks 4. Market power 5. Supply and demand trends
World Wide Fund for Nature (WWF, CH)	No	To examine if non-energy raw material supply bottlenecks could occur in the transition to a fully sustainable energy system	References EC methodology	WWF_2014: Materials which are vulnerable to supply bottlenecks are compiled by analysing six recent reports which identify critical materials for various sectors: • Ad-hoc Working Group on defining critical raw materials – Critical raw materials for the EU (2010) •The Hague Centre for Strategic Studies – Scarcity of Minerals: A strategic security issue (2010) • Joint Research Centre Institute for Energy and Transport – Supply chain bottlenecks in the Strategic Energy Technology Plan (2010) • Joint Research Centre Institute for Energy and Transport – Critical Metals in Strategic Energy Technologies (2011) • APS Panel on Public Affairs & The Materials Research Society – Energy Critical Elements: Securing Materials for Emerging Technologies (2011) • United Nations Environment Programme – Critical Metals for Future Sustainable Technologies and their Recycling Potential (2009)

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
Yale University (US)	No	To assess materials through the development of a criticality methodology and its use for selected materials	References EC methodology	Graedel_2012: Improvement of NRC_2008 methodology with three key dimensions: 1. Supply risk 2. Environmental implications 3. Vulnerability to supply restriction Depletion times (reserves). Indicators include: • Companion metal fraction • Policy potential index • Human development index • Worldwide governance indicators: Political stability • Global supply concentration • National economic importance • Percentage of population utilizing • Substitute performance & their availability • Environmental impact ratio • Net import reliance ratio • Global innovation index • LCA cradle-to-gate: 'human health' & 'ecosystems' Harper_2015: Based on Gradel_2012 with few modifications: • Vulnerability to supply restriction has been replaced by a "percentage of population utilizing" (PPU) with "material assets" (MA) at the global and national levels of analysis. • Two indicators were added to address vulnerabilities that might be inherent in the geographic distribution of a corporation's manufacturing facilities: - net import reliance ratio in the substitutability component - net import reliance in the susceptibility component

3.3 Papers describing criticality methodologies

The table below provides the same information as the table above (previous section). The methodologies here are sorted by literature source, rather than by organisation. Sorting by organisation gives more visibility to the actors and therefore further stresses the impact of the EC work. Sorting by paper removes duplications and therefore makes the information shorter, easier to structure and retrieve.

Short reference	**Objective of study**	**Reference/Use of EC methodology**	**Methodology basis**
AEA_2010	To assess future resource risks faced by UK business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	The two dimensions of criticality are consumption/production and scarcity/availability, based on the following indicators: • Availability of alternatives • Supply distribution • Supply domination • Extent of Geopolitical Influences • Press Coverage • Price Fluctuations
APS_2011	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of potential action by the United States to insure their availability		From Peck_2015: The term 'energy-critical element' is used to describe a class of chemical elements that currently appears critical to one or more new energy-related technologies. More specifically: 1. Elements that have not been widely extracted, traded, or utilised in the past 2. Elements that could significantly inhibit large-scale deployment of the new energy-related technologies
BGS_2011	To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials		An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on 4 criteria scored between 1 and 5. • Scarcity • Production concentration • Reserve distribution • Governance
BGS_2012	To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on seven criteria scored between 1 and 3. • Scarcity • Production concentration • Reserve distribution • Recycling Rate • Substitutability • Governance (top producing nation) • Governance (top reserve-hosting nation)
BP_2014	To improve understanding of the risk to the sustainability of each existing energy pathways induced by restricted supply of materials through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	Criticality is defined as the degree to which a material is necessary as a contributor to an energy pathway, based on: • Reserves, • Trades, • Ecological impact, • Processing,

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			• Substitutability, • Recyclability
BRGM_2015	To assess materials through the development of a criticality methodology	References EC methodology	Strategic importance for the French industry vs. risk of supply based on the following indicators: 1 - Demand and consumption 2 - Production and resources 3 - Substitutability 4 - Recycling 5 - Price 6 - Restrictions to international trade, Reglementations 7 - French production and resources 8 - French industry in the sector 9 - French trade and consumption
CBL_2011	To assess the impact of critical materials on the Dutch economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	The method follows a three-step approach: 1. classification of product groups based on the most detailed categorization used within the system of national accounts. 2. estimation of the amount of critical materials required to produce each product group. 3. determination to which extent the intermediate use of products by industries consists of critical materials.
DCGIS_2012	To assess companies' vulnerability with respect to CRM through a specific method/software. For companies with a high level of vulnerability towards CRM, a potential substitution path may be proposed.		Vulnerability of a company vs. risk of supply • Risk of supply relies on the following indicators: - Political stability of producing countries (WGI) - Level of production concentration (HHI) Concentration of producing countries Concentration of producing companies - Free trade limitations - Fraction of co-production (level of risk related to the one of the main metal) - Price volatility - French recycling capacity at End Of Life Level of development of recycling sector in France Rate of recycling Fraction of consumption from recycling • Vulnerability of a company relies on the following indicators: - Economic importance for the company - Capacity to handle price increase - Importance for company strategy - Characteristics of substitutes - Capacity of company to innovate - Understanding of supply-chain - Constraints, among others from regulations

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
DOD_2011	To assess U.S. vulnerabilities with respect to strategic and critical materials through the development of a criticality methodology and its use in the definition of a list of critical materials		The material shortfalls are estimated via a three step quantitative methodology: 1. Projection of demand on the economy for manufactured goods and services related to the military, industrial, and essential civilian sectors during the particular scenario. 2. Estimation of the quantities of strategic and critical materials needed to produce these goods and services. 3. Estimation of the amounts of domestic and reliable foreign supplies of strategic and critical materials available in the scenario, and compares them, on a time-phased basis, to the material demands computed in the second step. Any projected supply gaps (shortfalls) are identified. These shortfalls can become candidate goals for NDS inventory levels or targets to address with other mitigation strategies.
DOE_2010	To assess the role of rare earth metals and other materials in the clean energy economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	In analogy to the NRC_2008 methodology, the two-dimensional criticality ratings consider importance to clean energy vs. supply risk • Importance to clean energy encompasses: - Clean Energy Demand - Substitutability Limitations • The overall supply risk for each material is based on five categories of risk for the short and medium term: - Basic Availability - Competing Technology Demand - Political, Regulatory and Social Factors - Co-dependence on other Markets - Producer Diversity
DOE_2011	To assess the role of rare earth metals and other materials in the clean energy economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	In analogy to the NRC_2008 methodology, the two-dimensional criticality ratings consider importance to clean energy vs. supply risk • Importance to clean energy encompasses: - Clean Energy Demand - Substitutability Limitations • The overall supply risk for each material is based on five categories of risk for the short and medium term: - Basic Availability - Competing Technology Demand - Political, Regulatory and Social Factors - Co-dependence on other Markets - Producer Diversity
Duclos_2010 _paper	To assess critical materials to GE through the development of a methodology and its use for selected materials		The criticality diagram is constructed by plotting the "Impact of an Element Restriction on GE" versus the "Supply and Price Risk" based on the following indicators: - GE's percent of world supply - Impact on GE's revenue - GE's ability to substitute - Ability to pass through cost increases - Abundance in Earth's crust - Sourcing and geopolitical risk

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			- Co-production risk - Demand risk - Historic price volatility - Market substitutability
Duclos_2010_presentation	To assess critical materials to GE through the development of a methodology and its use for selected materials		Supply and Price Risk vs. impact on GE
Erdmann_2011b	To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC methodology	The two dimensions of criticality are vulnerability vs. risk of supply: • Vulnerability relies on 6 indicators: - Volume Relevance Germany's share of world consumption Change in the share of Germany in global consumption Change of German imports - Strategic relevance Sensitivity of the value chain in Germany Global demand momentum by technologies of the future Substitutability • Risk of supply relies on 7 indicators: - Country Risk Country risk for the imports of Germany Country risk for the global production Countries concentration of global reserves - Market Risk Corporate concentration of global production Ratio of global reserves to global production - Structural risk Share of the global primary and secondary production Recyclability
Frenzel_2015	To develop a general method for the assessment of the supply potential of elements.		Statistical and deterministic models are introduced to quantify both the variability in by-product concentrations in the relevant raw materials, as well as the effects of this variability on achievable recoveries.
Frondel_2006	To assess materials critical to the German economy through the development of a methodology		Three criteria determine if a raw material is currently classified as critical from a German perspective: (1) value of net imports (2) the concentration of production , which is measured using the Herfindahl index (3) political and economic risks of producing countries which is quantified using a range of relevant indicators of the world
Geoscience_Renault_2012	To assess materials through the development of a criticality methodology		Impact of supply restriction on Renault vs. risks on prices or supply (based on Yale methodology): • Risk factors influencing prices and/or supply: – Level of concentration of producers, and a governance indicator for economic and geopolitical stability of producing countries; – Environmental Performance Index; – Share of recycled material in consumption;

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			– Availability of coproducts; – Price volatility (over the last 3 years). • Factors having an impact of the activity of the constructor: – Technical importance of materials in cars; – Indicator on purchase price; – Substitutability; – Future price.
Gleich_2013	To assess materials through the development of a criticality methodology and its use for selected materials	References EC methodology	Methodology relies on: • Resource specific factors: - Country concentration, - Producer concentration, - World mine production, - Apparent consumption, - Secondary production, - Stocks. • And economic and demographic factors: - GDP, - World population, - Inflation, - Interest rate.
Goe_2014	To identify critical materials for photovoltaics in the US trough the development of a criticality methodology and its use	References EC methodology	The selection of the indicators listed below was motivated by broad applicability to the PV materials of interest and data availability. • Supply - Net import reliance - Herfindahl–Hirshmann index of primary material and ore producers - Recycling rate - Ratio of production to reserves • Environmental - CERCLA points - Primary embodied energy - Energy savings • Economic - Primary material price - Domestic consumption - Economic value by sector
Graedel_2012	To assess materials through the development of a criticality methodology	References EC methodology	Improvement of NRC_2008 methodology with three key dimensions: 1. Supply risk 2. Environmental implications 3. Vulnerability to supply restriction Depletion times (reserves). Indicators include: • Companion metal fraction • Policy potential index • Human development index • Worldwide governance indicators: Political stability

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			• Global supply concentration • National economic importance • Percentage of population utilizing • Substitute performance & their availability • Environmental impact ratio • Net import reliance ratio • Global innovation index • LCA cradle-to-gate: 'human health' & 'ecosystems'
Gsodam_2014	To carry out a material flow analysis of silver in Austria for the period 2012.		The MFA framework consists of a total offour main processes, each of which can be subdivided into various sub-processes. The four main processes in our system were: (1) The production process: Crude silver ore is extracted, separatedfrom its parent materials, and processed into refined silver. (2) The fabrication and manufacture process: Silver semi-productsare produced from refined silver. The silver semi-products arethen used in the manufacture process to make the finishedsilver products. Scrap is sent back to fabrication or to the pro-duction process for recycling. (3) The use process: In this process, silver is available either in theform of finished silver and silver alloy products or in the formof components of finished products. (4) The waste management process: The associated waste streamswithin this process are municipal solid waste, waste fromelectrical and electronic equipment, industrial waste, and haz-ardous waste. The discarded silver is recycled back into refinedsilver, treated thermally in an incineration plant or stored in landfills.
Habib_2015	To review, analyse and supplement the existing methodological approaches and to contribute to better understanding of the methodological aspects of criticality assessments and better interpretation of existing criticality assessment studies by taking a dynamic and technology specific approach.	References EC methodology	Adresses two concerns not considered by existing methods: A need for dynamic perspective of the supply risk with respect to both the geological and geopolitical aspects; The ability of methods to properly account for the importance of the supply risk of a given resource or the vulnerability of the studied system or technology to a disruption of the supply of the resource in question.
Harper_2015	To assess the criticality of the Geological Zinc, Tin, and Lead Family for the US based on Yale methodology	References EC methodology	Based on Gradel_2012 with few modifications: Vulnerability to supply restriction has been replaced by a "percentage of population utilizing" (PPU) with "material assets" (MA) at the global and national levels of analysis. Two indicators were added to address vulnerabilities that might be inherent in the geographic distribution of a corporation's manufacturing facilities: net import reliance ratio in the substitutability component net import reliance in the susceptibility component
Hatayama_2015	To define a list of critical metals for JP based on the definition and use of a criticality methodology	References EC methodology	Criticality assessment of metals has been developed to analyse a country's supply risk and vulnerability to supply restriction. The evaluation framework developed in this study included 13 criticality components within five risk categories: supply risk, price risk, demand risk, recycling restriction, and potential risk. • Supply risk - Depletion time - Concentration of reserves - Concentration of ore production

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			- Concentration of import trading partners - Sufficiency of mineral interest (additional factor to NEDO's methodology) • Price risk - Price change - Price variation • Demand risk - Mine production change - Domestic demand growth - Domestic demand growth for specific uses • Recycling restriction - Stockpiles - Recyclability • Potential risk - Possibility of usage restrictions
HCSS_2010	To discuss parameters impacting scarcity of minerals		Three criteria were used to assess which minerals may become scarce: First, the importance of these elements for the industrial sector, with special emphasis on high-tech industries. Second, the sample included elements for which few substitutes are known, as society is particularly vulnerable to shortages in these minerals. Third, the sample included elements which are crucial to emerging technologies, with particular emphasis on alternative energy and other 'green technologies'.
IDA_2010	To define a list of critical materials through the development and use of a criticality methodology, supporting US defence sector		The material shortfalls are estimated via a three step quantitative methodology: 1. Projection of demand on the economy for manufactured goods and services related to the military, industrial, and essential civilian sectors during the particular scenario. 2. Estimation of the quantities of strategic and critical materials needed to produce these goods and services. 3. Estimation of the amounts of domestic and reliable foreign supplies of strategic and critical materials available in the scenario, and compares them, on a time-phased basis, to the material demands computed in the second step. Any projected supply gaps (shortfalls) are identified. These shortfalls can become candidate goals for NDS inventory levels or targets to address with other mitigation strategies.
JOGMEG_2015	To assess the degree of importance of mineral commodities in Japan in order to contribute to secure stability of mineral resources, based on the EC methodology	Uses EC methodology	Method based on the European Commission's methodology of 2010: • Economic Importance - End uses of metals - Gross value added (GVA) - Price - Quantity of domestic demand - Quantity of world demand • Supply Risk - Import partner countries - Producing countries - Uneven distribution of reserve - Substitutability

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			- Recycle - Main product/by-product
JRC_2011	To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	The approach focuses on four criteria to evaluate risks for future supply chain bottlenecks for individual metals: 1. the likelihood of rapid global demand growth 2. limitations to expanding global production capacity in the short to medium term 3. the cross-country concentration of supply 4. political risk related to major supplying countries.
JRC_2013	To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	The approach focuses on four criteria to evaluate risks for future supply chain bottlenecks for individual metals: • Market factors - Limitations to expanding supply capacity - Likelihood of rapid global demand growth. • Geopolitical factors - Cross-country concentration of supply - Political risk related to major supplying countries
JRC_2015	To assess the sustainability of the production and supply of raw materials and primary energy carriers through the development of a methodology	References EC methodology	10 sustainability concerns are grouped into the following areas: - Environmental - Economic - Social/societal - Technical/technological
Kim_2015	To assess the materials consumption and requirement in wind energy system in the EU 27		The current consumption and future requirement of critical and precious materials were calculated and estimated using the wind power production dataset from ecoinvent and data from National Renewable Energy Action Plan (NREAP)
Knoeri_2013	To assess materials through the development of a criticality methodology	References EC methodology	Dynamic interactions between different possible demand and supply configurations
Mason_2011	To discuss factors impacting criticality, in view of assessing the impact of production peak on the Australia production of minerals and its impacts on the Australian economy		Evaluation of the impacts of changing patterns of mineral production through three criteria: 1. availability of a resource; 2. society's addiction to the resource; 3. and the possibility of finding alternatives
Mayer_2015	To discuss factors impacting criticality through the review and development of criticality methodologies	References EC methodology	Assessing supply risks of minerals criticality, based on Gleich_2013, in form of future price development and volatility.
MIT_Bae_2010	Korean government's approach to ensuring materials supply security.		Korea "rare" elements are subject to instability in supply and price fluctuations and selected based on rarity, instability, and concentration of supply and demand. The rarity is normalized to steel.
Moss_2013	To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	The approach focuses on four criteria to evaluate risks for future supply chain bottlenecks for individual metals: 1. the likelihood of rapid global demand growth 2. limitations to expanding global production capacity in the short to medium term 3. the cross-country concentration of supply 4. political risk related to major supplying countries.

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
Nieto_2013	To assess criticality for REE in petroleum refining materials through the development and use of a criticality methodology		Identification of five key supply risk factors (KSRFs): • Producer diversity • Resources risk factor • Demand from alternative applications • International trade environment • Environmental regulations
NRC_2008	To define a list of critical materials to the US economy through the development and use of a criticality methodology		Impact of Supply Restriction vs. Supply Risk, with indicators such as • Geologic Availability • Technical Availability • Environmental and Social Availability • Political Availability • Economic Availability
Oakdene_2008	To assess materials to ensure UK's military and economic sufficiency through the development of a criticality methodology and its use in the definition of a list of critical materials		Based on Yale methodology • 'Material risk' criteria: - global consumption levels (A) - lack of substitutability (B) - global warming potential (C) - total material requirement (D) • 'Supply risk' criteria: - scarcity (E) - monopoly supply (F) - political instability in key supplying regions (G) - vulnerability to the effects of climate change in key supplying regions (H)
OECD_2011	To assess critical materials for mobile devices through the development and use of a methodology		The report identifies four methodologies: (1) substance flow analysis; (2) life cycle assessment; (3) eco-efficiency and (4) a new proposed framework for incorporated social aspects.
Oeko_2009	To assess the impact of specific materials on future sustainable technologies (FST), such as renewable energies and energy efficient technologies, through the development and use of a criticality methodology.		Iterative process: • General prioritization (1st step): Critical metals are defined by: - High demand growth - High supply risks - Recycling restrictions • Focused prioritization regarding demand (2nd step): - Demand Growth • Focused prioritization regarding supply (3rd step): - Regional concentration of mining - Physical scarcities - Temporary scarcity - Structural or technical scarcity • Focused prioritization regarding recycling (4th step): - High scale of dissipative applications - Physical/chemical limitations for recycling

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			- Lack of suitable recycling technologies and/or infrastructures - Lack of prices incentives for recycling
Okada_2011	To serve as reference for those who supply metal resources or those who utilise metal resources, though the development and use of a criticality methodology	References EC methodology	Assessment of critical metals based on supply risk and on metal price trends • Supply risk: 1. Assessment based on Herfindahl-Hirschman Index (HHI) 2. Assessment employing Worldwide Governance Indicator (WGI) 3. Ores and Metals (Supply Chain): ores (extraction) and unprocessed metal (smelting): these will be examined employing an HHI. • Critical Risk as discerned from Price Trends 1. Medium and long term prices 2. 2010 monthly average price
PBL_2011	To review policy context dealing with resources scarcities	References EC methodology	Three dimensions of scarcity are distinguished: • Physical, for example: - Depletion of reserves - Insufficient renewable production / stocks • Economic, for example: - Malfunctioning markets (infrastructure and communication) - Harmonisation of production capacity in relation to demand • Political, for example: - Trade barriers / export disruptions - Conflicts.
Resnick_2011	To assess the criticality of materials for sustainable energy applications through the development of a methodology	References EC methodology	Critical materials are determined in terms of importance to the clean energy economy and risk of supply disruption
Roelich_2014	To monitor potential disruption in supply of critical materials which could endanger a transition to low-carbon infrastructure	References EC methodology	Two dimensions of risk are Supply disruption potential (P) vs. Exposure to disruption (E). „„• Supply disruption potential (P), is defined by the following 4 indicators: - Production-requirements imbalance - Companion fraction - Access - Environmental constraints „„• Exposure to disruption (E), is defined by the following 2 indicators: - Goal sensitivity - Price sensitivity
SATW_2010	To assess materials through the development of a criticality methodology and its use for selected materials		The following factors contribute to the criticality of materials: • Geologic • Geopolitics • Technologic • Economic • Social • Ecologic
Schneider_2013	To assess materials through the development of a criticality methodology and its use for selected materials	References EC methodology	Based on a life cycle perspective, the supply risk associated with resource use can be assessed, and bottlenecks within the supply chain can be identified. This analyses relies on the following indicators:

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			• Reserves • Recycling • Concentration of one activity • Economic stability • Demand growth • Trade barriers • Companion metal fraction
SEPA_2011	To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials		Production/consumption vs. availability/scarcity. Criteria considered were: • Combined consumption/production and scarcity/availability • Availability of alternatives • Supply distribution • Supply domination • Extent of geopolitical Influences • Press coverage • Price fluctuation
Skirrow_2013	To examine critical commodities from an Australian perspective and presents comprehensive technical (geological) information on Australia's resources and resource potential for these.		The assessments of resource potential are subjective judgements based on: • Level of criticality; • Australia's resources and potential for new discoveries; • Market size; and • Growth outlook.
Smith_1984	To identify potential commercialization barriers to new PV technologies by the identification of material shortages through a criticality assessment program.		The Critical Materials Assessment Program (CMAP) is an interactive computerized methodology that can assist in identifying potential material supply constraints due to the large-scale deployment of new technologies. Step 1: identification of materials requirements Step 2: identification of the cell production process Step 3: specification of the deployment scenarios Step 4: computation of the annual materials requirements Step 5: analysis of the materials production processes Step 6: characterization of the materials industry Step 7: assessment of the technology's impact Step 8: analysis of the results Step 9: study of the alternative options or mitigating strategies
TNO_2014	To assess the vulnerability of the Dutch economy and provide guidance to stakeholders regarding raw materials through the development of a qualitative and quantitative criticality method and its use.	Uses EC methodology	Assessment of the importance of the raw materials for the Dutch economy vs. supply risk + vulnerability on the basis of price volatility and mineral reserves. • Supply - Reserve/production - Concentration of materials (measured by HHI) of originating countries - Stability and governance (given by WGI) of source countries - Substitution options on product level - Sufficient Quality of sourcing materials - Future supply/demand ratio - Insight in complete supply chain? • Impact on profitability - Ability to pass through cost increases

Short reference	Objective of study	Reference/Use of EC methodology	Methodology basis
			- Percent of revenue impacted - Impact of price volatility of (raw) material at product and/or company level • External effects - EPI and HDI of sourcing countries - Impeding policy regulations present (for demand or supply)
VBW_2011	To raise awareness of businesses and governments through the development of a criticality methodology and its use in the definition of a list of critical materials		The Commodity Risk Index consists of eight criteria, which are grouped into quantitative and qualitative indicators: „„• Quantitative indicators: - Reserves-to-production ratio - Political stability in producing countries - Concentration of 3 main producing countries - Concentration of 3 main producing companies - Price risk „„• Qualitative indicators: - Importance for future technologies - Risk of strategic deployment - Substitutability
VW_2009	To assess materials supply risk through the development of a criticality methodology and its use for selected materials		The method is based on a combined evaluation of past and future supply and demand trends. Indicators for market assessment are: 1. Current supply and demand 2. Production costs 3. Geo strategic risks 4. Market power 5. Supply and demand trends
WWF_2014	To examine if non-energy raw material supply bottlenecks could occur in the transition to a fully sustainable energy system	References EC methodology	Materials which are vulnerable to supply bottlenecks are compiled by analysing six recent reports which identify critical materials for various sectors: „„• Ad-hoc Working Group on defining critical raw materials – Critical raw materials for the EU (2010) •„„ The Hague Centre for Strategic Studies – Scarcity of Minerals: A strategic security issue (2010) „„• Joint Research Centre Institute for Energy and Transport – Supply chain bottlenecks in the Strategic Energy Technology Plan (2010) „„• Joint Research Centre Institute for Energy and Transport – Critical Metals in Strategic Energy Technologies (2011) „„• APS Panel on Public Affairs & The Materials Research Society – Energy Critical Elements: Securing Materials for Emerging Technologies (2011) • United Nations Environment Programme – Critical Metals for Future Sustainable Technologies and their Recycling Potential (2009)

3.4 Organisations developing their own CRMs list

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
ADELPHI (DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC list	See Institute for Futures Studies and Technology Assessment (Erdmann_2011b) for further details.
AEA Technology plc (UK)		To assess future resource risks faced by UK business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	AEA_2010: High Risk: Aggregates / Fish / Indium / Lithium / Palm Oil / Phosphorus / Rare Earth Elements Medium Risk: Cobalt / Copper / Timber Low risk: Lead / Tin See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for follow-up and further details.
American Physical Society (APS, US)	No	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of potential action by the United States to insure their availability		APS_2011: Possible Energy-Critical Elements (ECEs): rare earth elements (REEs lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Tb), and lutetium (Lu)), scandium (Sc) and yttrium (Y), the platinum group elements (PGEs: ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir), and platinum (Pt)) gallium (Ga), germanium (Ge), selenium (Se), indium (In), and tellurium (Te), Cobalt (Co), helium (He), lithium (Li), rhenium (Re), silver (Ag)
British Geological Survey (BGS, UK)		To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials		See BGS_2011 for original list. BGS_2012: Silver (Ag); Aluminium (AI); Arsenic (As); Gold (Au); Barium (6a); Beryllium (Be); Bismuth (Bi); Diamond; Graphite; Cadmium (Cd); Cobalt (Co); Chromium (Cr); Copper (Cu); Fluorine (F); Iron (Fe); Gallium (Ga); Germanium (Ge); Mercury (Hg); Indium (In); Lithium (Li); Magnesium (Mg); Manganese (Mn); Molybdenum (Mo); Niobium (Nb); Nickel (Ni); Lead (Pb); Platinum Group Elements (PGE - Ruthenium (Ru), Palladium (Pd), Osmium (Os), Iridium (Ir) and Platinum (Pt)) ; Rhenium (Re); Rare Earth Elements (REE - Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb) and Lutetium (Lu)); Antimony (Sb); Selenium (Se); Tin (Sn); Strontium (Sr); Tantalum (Ta); Thorium (Th); Titanium (Ti); Uranium (U); Vanadium (V); Tungsten (W); Zinc (Zn); and Zirconium (Zr).
British Petroleum (BP, UK)		To improve understanding of the risk to the sustainability of each existing energy pathways induced by restricted supply of materials through the development of a criticality	References EC list	BP_2014: Ag, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Ga, Gd, Ge, Ho, In, K, La, Li, Lu, Mo, Nb, Nd, Ni, P, Pd, Pm, Pr, Pt, Re, Rh, Sc, Sm, Tb, Te, Tm, U, V, W, Y, Yb

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
		methodology and its use in the definition of a list of critical materials		
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, DE)		To assess materials critical to the German economy through the development of a methodology	References EC list	See Rheinisch-Westfälisches Institut für Wirtschaftsforschung (Frondel_2006) for further details.
Bundesministerium für Wirtschaft und Technologie (BMWi, DE)		To support the German economy. Here through the issue of the German raw material strategy	References EC list	See Fraunhofer-Institut für System- und Innovationsforschung (Fraunhofer_2009) for further details.
Bureau de Recherches Géologiques et Minières (BRGM, FR)		To assess materials critical to France through the development and use of a criticality methodology	Uses EC list	From BRGM_2015: Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Pt; Pd, Rh, W Zone of high criticality. Active watch recommended: Ir, Ru, Sb, Be Zone of medium criticality. Specialised watch recommended: Co, Li, Graphite, Ta, Se, Re, Mo, Te
Commissariat Général à la Stratégie et à la Prospective (CGSP, FR)		To identify raw materials of strategic economic importance for France and Europe	References EC list	Barreau_2013: Materials to watch following risk of supply shortage: Sb, Ga, Ge, In, Ni, Se, Te, Zr
Compagnie Européenne d'Intelligence Stratégique (CEIS, FR)		To assess materials critical to France through the use of a criticality methodology	References EC list	See Bureau de Recherches Géologiques et Minières (BRGM_2010_Te; BRGM_2011_Be; BRGM_2011_Mo; BRGM_2011_Re; BRGM_2011_Se; BRGM_2011_Ta; BRGM_2012_Graphite; BRGM_2012_Li; BRGM_2012_Sb; BRGM_2012_W; BRGM_2014_Co; BRGM_2014_PGM) for further details.
Defense National Stockpile Center (DNSC, US)	No	To define a list of critical materials through the development and use of a criticality methodology, supporting US defence sector		See Institute for Defense Analyses (IDA_2010) for further details.
Department Business Enterprise & Regulatory Reform (BERR, UK)		To assess materials to ensure UK's military and economic sufficiency through the development of a criticality methodology and its use in the definition of a list of critical materials		See Oakdene Hollins (Oakdene_2008) for further details.
Department for Environment, Food and Rural		To detail how the UK Government recognises private sector concerns about the availability of some raw materials, provides a framework for	References EC list	See AEA Technology plc (AEA_2010) for further details.

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
Affairs (DEFRA, UK)		business action to address resource risks, and sets out high level actions to build on the developing partnership between Government and businesses to address resource concerns		
Department of Defence (DoD, US)	No	To assess U.S. vulnerabilities with respect to strategic and critical materials through the development of a criticality methodology and its use in the definition of a list of critical materials		DOD_2011: Key 13 metals: Beryllium metal; Chromium, Ferro; Chromium Metal; Cobalt; Columbium; Germanium; Iridium (Platinum Group); Manganese ferro; Platinum (Platinum Group); Tantalum; Tin; Tungsten; Zinc
Department of Energy (DoE, US)	No	To assess the role of rare earth metals and other materials in the clean energy economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	DOE_2010: • Short Term - Critical: Dysprosium Europium Indium Terbium Neodymium Yttrium - Near-Critical: Cerium Lanthanum Tellurium - Not Critical: Cobalt Gallium Lithium Praseodymium Samarium • Medium Term - Critical: Dysprosium Europium Terbium Neodymium Yttrium - Near-Critical: Indium Lithium Tellurium - Not Critical: Cerium Cobalt Gallium Lanthanum Praseodymium Samarium See DOE_2011 for further details.
ECOFYS (NL)		To assess demand and supply of rare metals for the renewable energy sector	References EC list	See World Wide Fund for Nature (WWF_2014) for further details.
Environment Agency (EA, UK)		To turn waste into resources thereby supporting UK economy	Uses EC list	See Oakdene Hollins (EPOW_2011) for further details. See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for further details.
European Commission DG ENTR		To define a list of critical materials for the EU through the use of the EC methodology	References EC list	See Oakdene Hollins (Oakdene_2013) for further details.
Fraunhofer-Institut für System- und Innovationsforsc hung (ISI, DE)		To assess raw materials for emerging technologies by the development of a criticality methodology and its use in the definition of a list of critical materials	Uses EC list	Fraunhoffer_2009: 2030 demand above the total amount produced in the world today: Gallium; Neodymium; Indium; Germanium; Scandium; Platinum; Tantalum See Rheinisch-Westfälisches Institut für Wirtschaftsforschung (Frondel_2006) for further details. See Joint Research Center (JRC_2013) for further details. See Oakdene Hollins (Oakdene_2013) for further details.
Geoscience Australia (AU)	No	To examine critical commodities from an Australian perspective and presents	Uses EC list	Category one resource potential: Rare-earth elements (including scandium and yttrium); Platinum-group elements; Cobalt; Nickel; Chromium; Zirconium; Copper

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
		comprehensive technical (geological) information on Australia's resources and resource potential for these		Category two resource potential: Indium; Tungsten; Niobium; Molybdenum; Antimony; Lithium; Tantalum; Manganese; Titanium; Graphite; Tin; Beryllium; Bismuth; Thorium; Helium
Hague Centre for Strategic Studies (HCSS, NL)		To discuss parameters impacting scarcity of minerals and to review strategic mineral policies		HCSS_2010: Copper; Manganese; Nickel; Tin; Zinc; Gallium; Lithium; Molybdenum; Niobium; Hafnium; Tantalum; Tungsten; Zirconium; REEs; PGMs See JRC_2011 for further details.
House of Commons (HoC, UK)		To assess the vulnerability of the UK economy to supply risks for these critical materials, and issues around recycling, reuse, substitution, domestic extraction and production, and environmental concerns	References EC list	HoC_2011: Strategically important metals: Antimony, Beryllium, Chromium, Cobalt, Gallium, Germanium, Gold, Hafnium, Indium, Lithium, Magnesium, Nickel, Niobium, Platinum group metals (ruthenium, rhodium, palladium, osmium, iridium and platinum), Rare earth metals, Rhenium, Tantalum, Tellurium
Inha University (KR)	No	To assess the materials consumption and requirement in wind energy system in the EU 27	Uses EC list	Fluorspar has been the most consumed material to date, and will probably be the most required material in the future. Among other critical and valuable materials, the main materials used for current wind energy system are silver, magnesium, indium, gold and tantalum.
Institut der deutschen Wirtschaft Consult GmbH Köln (IW Consult, DE)		To raise awareness of businesses and governments through the development of a criticality methodology and its use in the definition of a list of critical materials		See Vereinigung der Bayerischen Wirtschaft (VBW_2011) for further details.
Institut für Zukunftsstudien und Technologiebewe rtung (IZT, DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC list	See Fraunhofer-Institut für System- und Innovationsforschung (Fraunhofer_2009) for further details. Erdmann_2011: Frequencies of criticality designations as critical > 2/3: Ce, Dy, Er, Eu, Gd, Ho, In, La, Lu, Nb, Nd, Pr, Pt, Rh, Ru, Sc, Sm, Tb, Tm, W, Y, Yb Erdmann_2011b: I. Low criticality (low supply risk, low vulnerability): diatomite, perlite & vermiculite, talc & Soapstone, kaolin, gypsum, mica, iron, limestone, bauxite, bentonite, lead, tantalum, manganese, phosphate II. Low supply risk, high vulnerability: aluminium, silicon, titanium, magnesite, magnesium, ilmenite, rutile & III. High supply risks, low vulnerability: diamond, borate IV Medium criticality (average supply risk, medium vulnerability). Graphite, selenium, strontium, barium, zirconium, molybdenum, zinc, hafnium, fluorspar, nickel, vanadium, cobalt, beryllium, lithium, copper, platinum, tellurium V. High criticality (high supply risk, high vulnerability): tungsten, rare earths, gallium, palladium, silver, tin, indium, niobium, chromium, bismuth

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
				VI. Highest criticality (very high supply risk, very high vulnerability): germanium, rhenium, antimony
Institute for Defense Analyses (IDA, US)	No	To define a list of critical materials through the development and use of a criticality methodology, supporting US defence sector		From IDA_2010: As referenced in DESIRE_2014: Al, Be, Bi, Co, Cr, Eu, F (fluorspar), Ga, Ge, Mn, Nb, Nd, Re, REE, Rh, Ru, Sb, Sm, Sn, Ta, Tb, W, Y
Joint Research Center (JRC, EC)		To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system and to assess the sustainability of the production and supply of raw materials and primary energy carriers through the development of methodologies		See JRC_2011 for initial list. JRC_2013: High: REE (Dy, Eu, Tb, Y, Pr, Nd), Gallium, Tellurium High-Medium: Graphite, Rhenium, Hafnium, Germanium, Platinum, Indium Medium: REE(La, Ce, Sm, Gd), Cobalt, Tantalum, Niobium, Vanadium, Tin, Chromium Medium-Low: Lithium, Molybdenum, Selenium, Silver Low: Nickel, Lead, Gold, Cadmium, Copper
KfW Bankengruppe (DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC list	See Institute for Futures Studies and Technology Assessment (Erdmann_2011b) for further details.
Korean Institute for Industrial Technology (KITECH, KR)	No	To ensure Korea materials supply security	References EC list	MIT_Bae_2010: In, Li, Ga, REE, Si, Mg, Ti, W, PGM, Ni, Zr
Materials Research Society (MRS, US)	No	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of potential action by the United States to insure their availability		See American Physical Society (APS_2011) for further details.
Metal Economics Research Institute (MERI, JP)	No	To serve as reference for those who supply metal resources or those who utilise metal resources, though the development and use of a criticality methodology	References EC list	Okada_2011: Critical metals where there is an assumed China risk: REE (particularly Dy, Tb, Y), Sb, W, Mg, Si, Ge, HG Critical metals judged on the basis of HHI changes: REE, Be, Mg, Hg, Si Critical metals judged on the basis of the WGI of countries having high share: REE, Sb, Hg, Sn, W, Mg, Ge, Si, V, As, PGMs Critical metals judged on the basis of medium-term price changes: Fe, REE, Pt, Sn, Pb, W Critical metals judged from 2010 average price changes: Pr, Nd, Dy, Sb, W, Sn, Cu, Pd
Ministry for Resources and Energy (AU)	No	To examine critical commodities from an Australian perspective and presents comprehensive technical (geological) information on Australia's resources and resource potential for these	Uses EC list	Category one resource potential: Rare-earth elements (including scandium and yttrium); Platinum-group elements; Cobalt; Nickel; Chromium; Zirconium; Copper Category two resource potential: Indium; Tungsten; Niobium; Molybdenum; Antimony; Lithium; Tantalum; Manganese; Titanium; Graphite; Tin; Beryllium; Bismuth; Thorium; Helium

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
Ministry of Economic Affairs (NL)		To assess the vulnerability of the Dutch economy and provide guidance to stakeholders regarding raw materials through the development of a qualitative and quantitative criticality method and its use	Uses EC list	See Netherlands Organisation for Applied Scientific Research (TNO_2014) for further details
National Institute of Advanced Industrial Science and Technology (AIST, JP)	No	To review Japanese policy oriented approach toward critical materials		Watanabe_2011: Strategic elements of Japan: B, Li, Be, Ti, V, Cr, Mn, Co, Ni, Ga, Ge, Se, Rb, Sr, Zr, Nb, Mo, Pd, In, Sb, Te, Cs, Ba, Hf, Ta, W, Re, Pt, Tl, Bi, REEs.
National Institute of Advanced Industrial Science and Technology (AIST, JP)	No	To define a list of critical metals for JP based on the definition and use of a criticality methodology	References EC list	Hatayama_2015: High criticality was found for neodymium. dysprosium. Indium and niobium
National Research Council (NRC, US)	No	To define a list of critical materials to the US economy through the development and use of a criticality methodology		NRC_2008: Ce, Dy, Er, Eu, Gd, Ho, In, La, Lu, Mn, Nb, Nd, Pr, Pt, Rh, Sm, Tb, Tm, Y, Yb
Netherlands Environmental Assessment Agency (PBL, NL)		To review policy context dealing with resources scarcities	References EC list	PBL_2011: Energy, food, minerals, water
Netherlands Organisation for Applied Scientific Research (TNO, NL)		To assess the vulnerability of the Dutch economy and provide guidance to stakeholders regarding raw materials through the development of a qualitative and quantitative criticality method and its use	Uses EC list	See Hague Centre for Strategic Studies (HCSS_2010) for further details. TNO_2014: Selected Materials for this study: Antimony Light Rare Earths Elements, Beryllium, Heavy Rare Earth Elements, Chromium, Silicon, Cobalt, Tungsten, Fluorspar, Tin, Phosphate Rock, Molybdenum, Indium, Silver, Lithium, Titanium dioxide, Natural Graphite, Vanadium, Niobium, Zinc, Platinum Group Metals, Coking coal
Northeastern University (US)	No	To assess the criticality of four nuclear energy metals based on Yale methodology	References EC list	See Yale University (Harper_2015b) for further details.
Northern Ireland Environment Agency (UK)		To assess future resource risks faced by Scottish business through the development of a criticality	References EC list	See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for further details.

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
		methodology and its use in the definition of a list of critical materials		
Oakdene Hollins (UK)		To define a list of critical materials for the EU through the use of the EC methodology	Uses EC list	Oakdene_2008: Top 8 Most insecure materials: Gold, Rhodium, Mercury, Platinum, Strontium, Silver, Antimony, Tin See Joint Research Center (JRC_2011) for further details. EPOW_2011: Critical material of opportunity for recovery: Antimony, Beryllium, Cobalt, Fluorspar, Gallium, Germanium, Graphite, Indium, Magnesium, Niobium, PGMs, REEs, Tantalum, Tungsten See Joint Research Center (JRC_2013) for further details. Oakdene_2013: Antimony, Beryllium, Borates, Chromium, Cobalt, Coking coal, Fluorspar, Gallium, Germanium, Indium, Lithium, Magnesite, Magnesium, Natural Graphite, Niobium, PGMs, Phosphate Rock, Rare Earths (Heavy), Rare Earths (Light), Silicon Metal, Tungsten
Oeko-Institut e.V. (DE)		To assess the impact of specific materials on future sustainable technologies (FST), such as renewable energies and energy efficient technologies, through the development and use of a criticality methodology		Oeko_2009: short-term (within next 5 years): Tellurium, Indium, Gallium mid-term (till 2020): Rare earths, Lithium, Tantalum, Palladium, Platinum, Ruthenium long-term (till 2050): Germanium, Cobalt
Polytechnic University of Tomsk (R)		To assess the materials consumption and requirement in wind energy system in the EU 27	Uses EC list	Fluorspar has been the most consumed material to date, and will probably be the most required material in the future. Among other critical and valuable materials, the main materials used for current wind energy system are silver, magnesium, indium, gold and tantalum.
Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI, DE)		To assess materials critical to the German economy through the development of a methodology		Frondel_2006: Examples of Copper / Aluminium / Iron / Zinc / Chrome / germanium / Vanadium / Fluorspar / Tantalum / Magnesite / Graphite / Platinium
Rochester Institute of Technology (US)	No	To identify critical materials for photovoltaics in the US trough the development of a criticality methodology and its use	Uses EC list	Goe_2014: Ge; Pt; Te; Se; As; Ag; Zn; In; Sn; Si; Cd; Ga; Al; Mo; Au; Cu; Fe
Samsung Engineering Co. (KR)	No	To assess the materials consumption and requirement in wind energy system in the EU 27	Uses EC list	Fluorspar has been the most consumed material to date, and will probably be the most required material in the future. Among other critical and valuable materials, the main materials used for current wind energy system are silver, magnesium, indium, gold and tantalum.
Science and Technology		To assess the vulnerability of the UK economy to supply risks for these critical materials, and issues around	References EC list	See House of Commons (HoC_2011) for further details.

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
Committee (STC, UK)		recycling, euse, substitution, domestic extraction and production, and environmental concerns		
Scotland & Northern Ireland Forum for Environmental Research (SNIFFER, UK)		To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	SEPA_2011: Aggregates, copper, cobalt, fish, Indium, Lead, Lithium, Palm Oil, Phosphorus, REEs, Timber, Tin
Scottish Environment Protection Agency (SEPA, UK)		To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for further details.
Stockholm Environment Institute (SEI, SE)		To assess the impact of the availability of five metals on the development of low carbon technologies	References EC list	SEI_2012: Severe risk of medium and long term CSD (cumulative supply deficits) of indium and tellurium; Moderate risk of medium term and severe risk of long term CSD of neodymium; Limited risk of long term CSD of cobalt and lithium.
United Nations Environment Programme (UNEP, UN)	No	To assess future sustainable technologies (FST), such as renewable energies and energy efficient technologies, which will make use of specific materials, through the development and use of a criticality methodology		See Oeko (Oeko_2009) for further details.
Universität Augsburg (DE)		To assess materials through the development of a criticality methodology and its use for selected materials		See British Petroleum (BP_2014) for further details. See Vereinigung der Bayerischen Wirtschaft (VBW_2011) for further details.
Université de Technologie de Troyes (FR)		To assess the materials consumption and requirement in wind energy system in the EU 27	Uses EC list	Fluorspar has been the most consumed material to date, and will probably be the most required material in the future. Among other critical and valuable materials, the main materials used for current wind energy system are silver, magnesium, indium, gold and tantalum.
University of Leeds (UK)		To monitor potential disruption in supply of critical materials which could endanger such a transition to low-carbon infrastructure		See Stockholm Environment Institute (SEI_2012) for further details
University of Technology, Kaunas (LT)		To identify the most important raw materials for Lithuanian economy in terms of economic importance, supply and environmental risks through the development of a criticality		Knašytė_2012: Crude oil, Natural gas, Sulphur, Caustic soda, Cast iron, Calcinated soda, Plywood, Tin, Building glass, Cotton, Aluminium, Polymers of vinyl chloride, Copper, Polystyrene and copolymers of styrene, Polypropylene, Steel and iron, Natural rubber, Lead, Zinc, Paper and paperboard, Polyethylene

Organisations	EU only?	Objective of organisation	Relation to EC list	EC list of Critical Materials
		methodology and its use in the definition of a list of critical materials		
Vereinigung der Bayerischen Wirtschaft (VBW, DE)		To raise awareness of businesses and governments through the development of a criticality methodology and its use in the definition of a list of critical materials		VBW_2011: Metals of high importance and risks for Bayern: Rare earth metals, tungsten, cobalt, platinum group (Pd , Pt), tin, lithium, molybdenum, indium, magnesium
World Wide Fund for Nature (WWF, CH)	No	To examine if non-energy raw material supply bottlenecks could occur in the transition to a fully sustainable energy system	References EC list	WWF_2014: Co and Li
Yale University (US)	No	To assess materials through the development of a criticality methodology and its use for selected materials		Nassar_2012 (as per Schneider_2013): High Criticality: Silver Low Criticality: Copper, Gold Nuss_2014: Modest Criticality: V, Cr, Mn, Nb Low Criticality: Fe

3.5 Sources providing information on CRMs lists

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
AEA_2010	To assess future resource risks faced by UK business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	High Risk: Aggregates / Fish / Indium / Lithium / Palm Oil / Phosphorus / Rare Earth Elements Medium Risk: Cobalt / Copper / Timber Low risk: Lead / Tin
APS_2011	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of potential action by the United States to insure their availability		Possible Energy-Critical Elements (ECEs): rare earth elements (REEs lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Tb), and lutetium (Lu)), scandium (Sc) and yttrium (Y), the platinum group elements (PGEs: ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir), and platinum (Pt)) gallium (Ga), germanium (Ge), selenium (Se), indium (In), and tellurium (Te), Cobalt (Co), helium (He), lithium (Li), rhenium (Re), silver (Ag)
Barreau_2013	To identify raw materials of strategic economic importance for France and Europe	References EC list	Materials to watch following risk of supply shortage: Sb, Ga, Ge, In, Ni, Se, Te, Zr
BGS_2011	To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials		Ag; Al; As; Au; B; Ba; Be; Bi; Br; C (coal, diamond and graphite); Ca; Cd; CI; Co; Cr; Cu; F; Fe; Ga; Ge; He; Hg; t In, K; Li, Mgi Mn; Mo; Na; Nb; Ni; P; Pb; PGE (Ru, Pd, Os, Ir and Pt) ; Re; REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu); S; Sb; Se; Sn; Sr; Ta, Th; Ti; U; V; W; Zn; and Zr.
BGS_2012	To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials		Silver (Ag); Aluminium (AI); Arsenic (As); Gold (Au); Barium (6a); Beryllium (Be); Bismuth (Bi); Diamond; Graphite; Cadmium (Cd); Cobalt (Co); Chromium (Cr); Copper (Cu); Fluorine (F); Iron (Fe); Gallium (Ga); Germanium (Ge); Mercury (Hg); Indium (In); Lithium (Li); Magnesium (Mg); Manganese (Mn); Molybdenum (Mo); Niobium (Nb); Nickel (Ni); Lead (Pb); Platinum Group Elements (PGE - Ruthenium (Ru), Palladium (Pd), Osmium (Os), Iridium (Ir) and Platinum (Pt)) ; Rhenium (Re); Rare Earth Elements (REE - Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb) and Lutetium (Lu)); Antimony (Sb); Selenium (Se); Tin (Sn); Strontium (Sr); Tantalum (Ta); Thorium (Th); Titanium (Ti); Uranium (U); Vanadium (V); Tungsten (W); Zinc (Zn); and Zirconium (Zr).
BP_2014	To improve understanding of the risk to the sustainability of each existing energy pathways induced by restricted supply of materials through the development of a criticality methodology and its use in	References EC list	Ag, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Ga, Gd, Ge, Ho, In, K, La, Li, Lu, Mo, Nb, Nd, Ni, P, Pd, Pm, Pr, Pt, Re, Rh, Sc, Sm, Tb, Te, Tm, U, V, W, Y, Yb

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
	the definition of a list of critical materials		
BRGM_2010_Te	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Te
BRGM_2011_Be	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Be Zone of medium criticality. Specialised watch recommended:
BRGM_2011_Mo	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Mo
BRGM_2011_Re	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Re
BRGM_2011_Se	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Se
BRGM_2011_Ta	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Ta
BRGM_2012_Graphite	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Graphite
BRGM_2012_Li	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Li
BRGM_2012_Sb	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Sb Zone of medium criticality. Specialised watch recommended:
BRGM_2012_W	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: W

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
			Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended:
BRGM_2014_Co	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Zone of high criticality. Active watch recommended: Zone of medium criticality. Specialised watch recommended: Co
BRGM_2014_PGM	To assess materials through the use of a criticality methodology	References EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: Pt; Pd, Rh Zone of high criticality. Active watch recommended: Ir, Ru Zone of medium criticality. Specialised watch recommended:
BRGM_2015	To assess materials through the development of a criticality methodology	Uses EC list	Zone of high criticality. Actions to be undertaken by the government. Follow-up of the evolution of criticality indicators: W Zone of high criticality. Active watch recommended: Sb Zone of medium criticality. Specialised watch recommended:
DOD_2011	To assess U.S. vulnerabilities with respect to strategic and critical materials through the development of a criticality methodology and its use in the definition of a list of critical materials		Key 13 metals: Beryllium metal; Chromium, Ferro; Chromium Metal; Cobalt; Columbium; Germanium; Iridium (Platinum Group); Manganese ferro; Platinum (Platinum Group); Tantalum; Tin; Tungsten; Zinc
DOE_2010	To assess the role of rare earth metals and other materials in the clean energy economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	Short Term Critical: Dysprosium Europium Indium Terbium Neodymium Yttrium Near-Critical: Cerium Lanthanum Tellurium Not Critical: Cobalt Gallium Lithium Praseodymium Samarium Medium Term Critical: Dysprosium Europium Terbium Neodymium Yttrium Near-Critical: Indium Lithium Tellurium Not Critical: Cerium Cobalt Gallium Lanthanum Praseodymium Samarium
DOE_2011	To assess the role of rare earth metals and other materials in the clean energy economy through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	Critical in the short term: dysprosium, terbium, europium, neodymium and yttrium Near-Critical in the short term: cerium, indium, lanthanum and tellurium.
EPOW_2011	To assess the impact of the EU's list of 14 critical materials on the economy of south of England through the development of a criticality methodology and its use.	Uses EC list	Critical material of opportunity for recovery: Antimony, Beryllium, Cobalt, Fluorspar, Gallium, Germanium, Graphite, Indium, Magnesium, Niobium, PGMs, REEs, Tantalum, Tungsten
Erdmann_2011	To review criticality methodologies		Frequencies of criticality designations as critical > 2/3: Ce, Dy, Er, Eu, Gd, Ho, In, La, Lu, Nb, Nd, Pr, Pt, Rh, Ru, Sc, Sm, Tb, Tm, W, Y, Yb

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
Erdmann_2011b	To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC list	I. Low criticality (low supply risk, low vulnerability): diatomite, perlite & vermiculite, talc & Soapstone, kaolin, gypsum, mica, iron, limestone, bauxite, bentonite, lead, tantalum, manganese, phosphate II. Low supply risk, high vulnerability: aluminium, silicon, titanium, magnesite, magnesium, ilmenite, rutile & III. High supply risks, low vulnerability: diamond, borate IV Medium criticality (average supply risk, medium vulnerability). Graphite, selenium, strontium, barium, zirconium, molybdenum, zinc, hafnium, fluorspar, nickel, vanadium, cobalt, beryllium, lithium, copper, platinum, tellurium V. High criticality (high supply risk, high vulnerability): tungsten, rare earths, gallium, palladium, silver, tin, indium, niobium, chromium, bismuth VI. Highest criticality (very high supply risk, very high vulnerability): germanium, rhenium, antimony
Fraunhoffer_2009	To assess raw materials for emerging technologies by the use of a criticality methodology for the definition of a list of critical materials		2030 demand above the total amount produced in the world today: Gallium; Neodymium; Indium; Germanium; Scandium; Platinum; Tantalum
Frondel_2006	To assess materials critical to the German economy through the development of a methodology		Examples of Copper / Aluminium / Iron / Zinc / Chrome / Germanium / Vanadium / Fluorspar / Tantalum / Magnesite / Graphite / Platinium
Goe_2014	To identify critical materials for photovoltaics in the US trough the development of a criticality methodology and its use	Uses EC list	Ge; Pt; Te; Se; As; Ag; Zn; In; Sn; Si; Cd; Ga; Al; Mo; Au; Cu; Fe
Harper_2015	To assess the criticality of the Geological Zinc, Tin, and Lead Family for the US based on Yale methodology	References EC list	Pb and Zn have the lowest SR for the medium term and Pb the lowest SR for the long term. In and Ge production have the highest environmental burdens, mainly as a result of emissions from Zn smelting and subsequent metals purification and recovery from Zn leaching residues. VSR is highest for Pb at the global and national levels.
Harper_2015b	To assess the criticality of four nuclear energy metals based on Yale methodology	References EC list	The SR score is the highest for zirconium over both the medium term (i.e., 5–10 years) and the long term(i.e., a few decades). The cradle-to-gate EI score is highest for uranium, followed by hafnium and thenthorium, with impacts due to a combination of on-site emissions and upstream burdens from the use ofenergy and materials during mineral processing and refining. Uranium has the highest VSR score at thenational level, and the second highest at the global level. Zirconium is the most vulnerable at the global level.
Hatayama_2015	To define a list of critical metals for JP based on the definition and use of a criticality methodology	References EC list	High criticality was found for neodymium. dysprosium. Indium and niobium
HCSS_2010	To discuss parameters impacting scarcity of minerals		Copper; Manganese; Nickel; Tin; Zinc; Gallium; Lithium; Molybdenum; Niobium; Hafnium; Tantalum; Tungsten; Zirconium; REEs; PGMs

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
HoC_2011	To assess the vulnerability of the UK economy to supply risks for these critical materials, and issues around recycling, reuse, substitution, domestic extraction and production, and environmental concerns	References EC list	Strategically important metals: Antimony, Beryllium, Chromium, Cobalt, Gallium, Germanium, Gold, Hafnium, Indium, Lithium, Magnesium, Nickel, Niobium, Platinum group metals (ruthenium, rhodium, palladium, osmium, iridium and platinum), Rare earth metals, Rhenium, Tantalum, Tellurium
IDA_2010	To define a list of critical materials through the development and use of a criticality methodology, supporting US defence sector		From IDA_2010: As referenced in DESIRE_2014: Al, Be, Bi, Co, Cr, Eu, F (fluorspar), Ga, Ge, Mn, Nb, Nd, Re, REE, Rh, Ru, Sb, Sm, Sn, Ta, Tb, W, Y
JRC_2011	To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	tellurium, indium, tin, hafnium, silver, dysprosium, gallium, neodymium, cadmium, nickel, molybdenum, vanadium, niobium and selenium.
JRC_2013	To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	High: REE (Dy, Eu, Tb, Y, Pr, Nd), Gallium, Tellurium High-Medium: Graphite, Rhenium, Hafnium, Germanium, Platinum, Indium Medium: REE(La, Ce, Sm, Gd), Cobalt, Tantalum, Niobium, Vanadium, Tin, Chromium Medium-Low: Lithium, Molybdenum, Selenium, Silver Low: Nickel, Lead, Gold, Cadmium, Copper
Kim_2015	To assess the materials consumption and requirement in wind energy system in the EU 27	Uses EC list	Fluorspar has been the most consumed material to date, and will probably be the most required material in the future. Among other critical and valuable materials, the main materials used for current wind energy system are silver, magnesium, indium, gold and tantalum.
Knašytė_2012	To identify the most important raw materials for Lithuanian economy in terms of economic importance, supply and environmental risks through the development of a criticality methodology and its use in the definition of a list of critical materials		Crude oil, Natural gas, Sulphur, Caustic soda, Cast iron, Calcinated soda, Plywood, Tin, Building glass, Cotton, Aluminium, Polymers of vinyl chloride, Copper, Polystyrene and copolymers of styrene, Polypropylene, Steel and iron, Natural rubber, Lead, Zinc, Paper and paperboard, Polyethylene
MIT_Bae_2010	Korean government's approach to ensuring materials supply security.		In, Li, Ga, REE, Si, Mg, Ti, W, PGM, Ni, Zr
Moss_2013	To assess the role of raw materials as a bottleneck to the decarbonisation of the European Energy system through the	References EC list	tellurium, indium, tin, hafnium, silver, dysprosium, gallium, neodymium, cadmium, nickel, molybdenum, vanadium, niobium and selenium.

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
	development of a criticality methodology and its use in the definition of a list of critical materials		
NRC_2008	To define a list of critical materials to the US economy through the development and use of a criticality methodology		Ce, Dy, Er, Eu, Gd, Ho, In, La, Lu, Mn, Nb, Nd, Pr, Pt, Rh, Sm, Tb, Tm, Y, Yb
Nuss_2014	To assess criticality of Iron and its principal alloying elements through the use of Yale methodology	References EC list	Modest Criticality: V, Cr, Mn, Nb Low Criticality: Fe
Oakdene_2008	To assess materials to ensure UK's military and economic sufficiency through the development of a criticality methodology and its use in the definition of a list of critical materials		Top 8 Most insecure materials: Gold, Rhodium, Mercury, Platinum, Strontium, Silver, Antimony, Tin
Oakdene_2013	To define a list of critical materials for the EU through the use of the EC methodology	References EC list	Antimony, Beryllium, Borates, Chromium, Cobalt, Coking coal, Fluorspar, Gallium, Germanium, Indium, Lithium, Magnesite, Magnesium, Natural Graphite, Niobium, PGMs, Phosphate Rock, Rare Earths (Heavy), Rare Earths (Light), Silicon Metal, Tungsten
Oeko_2009	To assess the impact of specific materials on future sustainable technologies (FST), such as renewable energies and energy efficient technologies, through the development and use of a criticality methodology.		short-term (within next 5 years): Tellurium, Indium, Gallium mid-term (till 2020): Rare earths, Lithium, Tantalum, Palladium, Platinum, Ruthenium long-term (till 2050): Germanium, Cobalt
Okada_2011	To serve as reference for those who supply metal resources or those who utilise metal resources, though the development and use of a criticality methodology	References EC list	Critical metals where there is an assumed China risk: REE (particularly Dy, Tb, Y), Sb, W, Mg, Si, Ge, HG Critical metals judged on the basis of HHI changes: REE, Be, Mg, Hg, Si Critical metals judged on the basis of the WGI of countries having high share: REE, Sb, Hg, Sn, W, Mg, Ge, Si, V, As, PGMs Critical metals judged on the basis of medium-term price changes: Fe, REE, Pt, Sn, Pb, W Critical metals judged from 2010 average price changes: Pr, Nd, Dy, Sb, W, Sn, Cu, Pd
Panousi_2015	To assess the criticality of specific metals through the use of the methodology developed at Yale	References EC list	The SR score is the highest for zirconium over both the medium term (i.e., 5–10 years) and the long term(i.e., a few decades). The cradle-to-gate EI score is highest for uranium, followed by hafnium and then thorium, with impacts due to a combination of on-site emissions and upstream burdens from the use of energy and materials during mineral processing and refining. Uranium has the highest VSR score at the national level, and the second highest at the global level. Zirconium is the most vulnerable at the global level.

Short reference	Objective of study	Reference/Use of EC methodology	Critical Materials
PBL_2011	To review policy context dealing with resources scarcities	References EC list	Energy, food, minerals, water
SEI_2012	To assess the impact of the availability of five metals on the development of low carbon technologies.	References EC list	Severe risk of medium and long term CSD (cumulative supply deficits) of indium and tellurium; Moderate risk of medium term and severe risk of long term CSD of neodymium; Limited risk of long term CSD of cobalt and lithium.
SEPA_2011	To assess future resource risks faced by Scottish business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC list	Aggregates, copper, cobalt, fish, Indium, Lead, Lithium, Palm Oil, Phosphorus, REEs, Timber, Tin
Skirrow_2013	To examine critical commodities from an Australian perspective and presents comprehensive technical (geological) information on Australia's resources and resource potential for these.	Uses EC list	Category one resource potential: Rare-earth elements (including scandium and yttrium); Platinum-group elements; Cobalt; Nickel; Chromium; Zirconium; Copper Category two resource potential: Indium; Tungsten; Niobium; Molybdenum; Antimony; Lithium; Tantalum; Manganese; Titanium; Graphite; Tin; Beryllium; Bismuth; Thorium; Helium
TNO_2014	To assess the vulnerability of the Dutch economy and provide guidance to stakeholders regarding raw materials through the development of a qualitative and quantitative criticality method and its use.	Uses EC list	Selected Materials for this study: Antimony Light Rare Earths Elements, Beryllium, Heavy Rare Earth Elements, Chromium, Silicon, Cobalt, Tungsten, Fluorspar, Tin, Phosphate Rock, Molybdenum, Indium, Silver, Lithium, Titanium dioxide, Natural Graphite, Vanadium, Niobium, Zinc, Platinum Group Metals, Coking coal
VBW_2011	To raise awareness of businesses and governments through the development of a criticality methodology and its use in the definition of a list of critical materials		Metals of high importance and risks for Bayern: Rare earth metals, tungsten, cobalt, platinum group (Pd , Pt), tin, lithium, molybdenum, indium, magnesium
Watanabe_2011	Japanese policy oriented approach toward critical materials		Strategic elements of Japan: B, Li, Be, Ti, V, Cr, Mn, Co, Ni, Ga, Ge, Se, Rb, Sr, Zr, Nb, Mo, Pd, In, Sb, Te, Cs, Ba, Hf, Ta, W, Re, Pt, Tl, Bi, REEs.
WWF_2014	To examine if non-energy raw material supply bottlenecks could occur in the transition to a fully sustainable energy system	References EC list	Co and Li

3.6 References

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Achzet_2013	B. Achzet, C. Helbig. 2013. How to evaluate raw material supply risks—an overview. Resources Policy, 38, 435-447		Yes		Yes	Yes		Yes
AEA_2010	Defra (2010) Review of the Future Resource Risks Faced by UK Businesses and an Assessment of Future Viability (SCP0905/EV0458).		Yes					
AICHE_2012	ACS Presidential Symposium on Ensuring the Sustainability of Critical Materials and Alternatives				Yes			Yes
APS_2011	APS/MRS (2011) Energy Critical Elements: Securing Materials for Emerging Technologies.		Yes					
Asif_2015	F. M.A. Asif, A. Rashid, C. Bianchi, C. M. Nicolescu, System dynamics models for decision making in product multiple lifecycles, Resources, Conservation and Recycling, Volume 101, August 2015, Pages 20–33		Yes					
Ayres_2013	R.U. Ayres, L. Talens Peiró, 2013 Material efficiency: rare and critical metals. Phil Trans R Soc A 371: 20110563. http://dx.doi.org/10.1098/rsta.2011.0563	Yes						
Baldi_2014	L. Baldi, M. Peri, D. Vandone, Clean energy industries and rare earth materials: Economic and financial issues, Energy Policy, Volume 66, March 2014, Pages 53-61, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2013.10.067.		Yes			Yes		Yes
Barreau_2013	B. Barreau, G. Hossie, S. Lutfalla, Approvisionnements en métaux critiques Un enjeu pour la compétitivité des industries française et européenne, Document de travail n°2013-04, Commissariat général à la stratégie et à la prospective, juillet 2013				Yes			Yes
Beck_2015	G. Beck, S. Barcikowski, V.S.K. Chakravadhanula, M. Comesaña-Hermo, M. Deng, M. Farle, M. Hilgendorff, J. Jakobi, J. Janek, L. Kienle, B. Mogwitz, T. Schubert, F. Stiemke, An approach for transparent and electrically conducting coatings: A transparent plastic varnish with nanoparticulate magnetic additives, Thin Solid Films, Volume 595, Part A, 30 November 2015, Pages 96-107, ISSN 0040-6090, http://dx.doi.org/10.1016/j.tsf.2015.10.059.		Yes					
Beylot_2015	A. Beylot, J. Villeneuve, Assessing the national economic importance of metals: An Input–Output approach to the case of copper in France, Resources Policy, Volume 44, June 2015, Pages 161-165, ISSN 0301-4207, http://dx.doi.org/10.1016/j.resourpol.2015.02.007.					Yes		
BGS_2011	British Geological Survey (BGS): British Geological Survey, 2011, Risk list 2011		Yes		Yes			Yes
BGS_2012	British Geological Survey (BGS): British Geological Survey, 2012, Risk list 2012		Yes			Yes		
Binnemans_2013	K. Binnemans, P. T. Jones, B. Blanpain, T. Van Gerven, Y. Yang, A. Walton, M. Buchert, Recycling of rare earths: a critical review, Journal of Cleaner Production, Volume 51, 15 July 2013, Pages 1-22, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2012.12.037.		Yes			Yes		
Blissett_2014	R.S. Blissett, N. Smalley, N.A. Rowson, An investigation into six coal fly ashes from the United Kingdom and Poland to evaluate rare earth element content, Fuel, Volume 119, 1 March 2014, Pages 236-239, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2013.11.053.					Yes		
BMBF_2012	Bundesministerium für Bildung und Forschung (BMBF) (2012): Wirtschaftsstrategische Rohstoffe für den Hightech-Standort Deutschland. Forschungs- und Entwicklungsprogramm des BMBF für neue Rohstofftechnologien.		Yes			Yes		
BMWFW_2014	ÖSTERREICHISCHES MONTAN-HANDBUCH 2014 Bergbau - Rohstoffe - Grundstoffe - Energie, 88. Jahrgang, Wien 2014, ISBN 978-3-901074-37-0		Yes					

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
BMWi_2010	Bundesministerium für Wirtschaft und Technologie (BMWi) (2010): Rohstoffstrategie der Bundesregierung. Sicherung einer nachhaltigen Rohstoffversorgung Deutschlands mit nicht-energetischen mineralischen Rohstoffen.	Yes	Yes		Yes	Yes		Yes
BP_2014	Zepf V., Reller A., Rennie C., Ashfield M. & Simmons J., BP (2014): Materials critical to the energy industry. An introduction. First published 2011, revised 2014. isbn 978-0-9928387-0-6					Yes		Yes
BRGM_2010_Te	Audion A.S., Labbé J.F., avec la collaboration extérieure de la Compagnie Européenne d'Intelligence Stratégique (CEIS) (2010) - Panorama mondial 2010 du marché du tellure. Rapport Public. BRGM/RP-60206-FR, 71 p., 21 fig., 11 tabi.					Yes		Yes
BRGM_2011_Be	Christmann P., Corbineau L, Labbé J.F et Monthel J., avec la collaboration extérieure de la Compagnie Européenne d'Intelligence Stratégique (CEIS) (2011) - Panorama mondial 2010 du marché du béryllium. BRGM/RP-60203-FR, 60 p., 15 fig., 7 tabi.					Yes		Yes
BRGM_2011_Mo	Barthélémy F., Christmann P. (2011) - Panorama 2010 du marché du Molybdène. BRGM/RP-60204-FR, 59 p. 14 fig., 5 tabi.					Yes		Yes
BRGM_2011_Re	Audion A.S., Martel-Jantin B. (2011) - Panorama mondial 2010 du marché du rhénium. Rapport final. BRGM/RP-60205-FR, 76 p., 23 fig., 15 tabi.					Yes		Yes
BRGM_2011_Se	Labbé J.F. et Christmann P., avec la collaboration extérieure de la Compagnie Européenne d'Intelligence Stratégique (CEIS) (2011) - Panorama mondial 2010 du marché du sélénium. BRGM/RP-60202-FR, 90 p., 18 fig., 17 tabi.					Yes		Yes
BRGM_2011_Ta	AUDION AS., PIANTONE P., avec la collaboration extérieure de la Compagnie Européenne d'Intelligence Stratégique (CEIS) (2011) - Panorama 2011 du marché du tantale. Rapport Public. BRGM/RP-61343-FR, 91 p., 20 fig., 15 tabi., 1 annexe confidentielle					Yes		Yes
BRGM_2012_Graphite	Barthélémy F., Labbé J.F. et Picot J.C. (2012) - Panorama 2011 du marché du graphite naturel. BRGM/RP-61339-FR, 91 p. 15 fig., 20 tabi.					Yes		Yes
BRGM_2012_Li	Labbé J.F. et Daw G. (2012) - Panorama 2011 du marché du lithium. Rapport public. BRGM/RP-61340-FR. 154 p., 51 fig., 29 tab.					Yes		Yes
BRGM_2012_Sb	AUDION A.S, avec la collaboration extérieure de la Compagnie Européenne d'Intelligence Stratégique (CEIS) (2012) - Panorama mondial 2011 du marché de l'antimoine. Rapport public. BRGM/RP-61342-FR, 82 p., 22 fig., 17 tabi.					Yes		Yes
BRGM_2012_W	Audion A.S., Labbé J.F., avec la collaboration extérieure de la Compagnie Européenne d'Intelligence Stratégique (CEIS) (2012) - Panorama mondial 2011 du marché du tungstène. Rapport Public. BRGM/RP-61341-FR, 108 p., 29 fig., 16 tabi.					Yes		Yes
BRGM_2014_Co	Audion A.S., Hocquard G., Labbé J.F., avec la collaboration de Dupuy J.J. (2014) - Panorama mondial 2013 du marché du cobalt. Rapport public. BRGM/RP-63626-FR, 156 p., 45 fig., 33 tabi.					Yes		Yes
BRGM_2014_PGM	Labbé J.F., avec la collaboration de Dupuy J.J. (2014) - Panorama mondial 2012 du marché des platinoides. Rapport public. BRGM/RP-63169-FR, 215 p., 78 fig., 42 tab.		Yes		Yes		Yes	Yes
BRGM_2015	Christmann P., Labbé J.F. (2015) - Notice de réalisation et d'utilisation des fiches de synthèse sur la criticité des matières premières minérales non-énergétiques - Rapport Public. BRGM/RP-64661-FR, 61 p., 4 fig., 3 annexes.		Yes					
Bruckner_2012	M. Bruckner, S. Giljum, C. Lutz, K. Svenja Wiebe, Materials embodied in international trade – Global material extraction and consumption between 1995 and 2005, Global Environmental Change, Volume 22, Issue 3, August 2012, Pages 568-576, ISSN 0959-3780, http://dx.doi.org/10.1016/j.gloenvcha.2012.03.011.	Yes	Yes			Yes		

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Buijs_2011	B. Buijs and H. Sievers, Critical Thinking about Critical Minerals Assessing risks related to resource security, EU FP7 POLINARES project grant agreement n°244516, November 2011	Yes	Yes			Yes		
Buijs_2012	B. Buijs, H. Sievers, L. A. Tercero Espinoza, Limits to the critical raw materials approach, Proceedings of the ICE - Waste and Resource Management, Volume 165, Issue 4, p. 201-208, November 2012		Yes				Yes	
Bustamante_2014	M. L. Bustamante, G. Gaustad, Challenges in assessment of clean energy supply-chains based on byproduct minerals: A case study of tellurium use in thin film photovoltaics, Applied Energy, Volume 123, 15 June 2014, Pages 397-414, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2014.01.065.						Yes	
BuZa_2013	Netherlands raw materials strategy		Yes		Yes		Yes	
Calvo_2016	G. Calvo, A. Valero, A. Valero, Material flow analysis for Europe: An exergoecological approach, Ecological Indicators, Volume 60, January 2016, Pages 603-610, ISSN 1470-160X, http://dx.doi.org/10.1016/j.ecolind.2015.08.005.	Yes	Yes			Yes		
CBL_2011	Statsistics Netherlands, Centre for Policy Related Statistics. Critical Materials in the Dutch Economy; Preliminary results; The Hague, Netherlands, 2010.					Yes		
Chakhmouradian_2015	A. R. Chakhmouradian, M. P. Smith, J. Kynicky, From “strategic” tungsten to “green” neodymium: A century of critical metals at a glance, Ore Geology Reviews, Volume 64, January 2015, Pages 455-458, ISSN 0169-1368, http://dx.doi.org/10.1016/j.oregeorev.2014.06.008.					Yes		
CIM_Ferron_2013	C.J. Ferron, P. Henry, a review of the recycling of rare earth metals, proceedings of the 52nd Conference of Metallurgists		Yes					
CIM_King_2013	A. H. King and R. G. Eggert, Critical Materials Institute, proceedings of the 52nd Conference of Metallurgists					Yes		
CIM_Zampini_2013	J. Zampini, Y. Kim, M.-A. Van Ende and I. Jung, RECYCLING OF Nd FROM Nd PERMANENT MAGNET USING LIQUID Mg SOLVENT, proceedings of the 52nd Conference of Metallurgists						Yes	
CRF_2015	S. Avataneo, Key aspects of raw materials in the automotive sector, applications monitoring and substitution trends, Ecomundo 2015, Rimini, Italy	Yes	Yes			Yes		
CRM_InnoNet_2015	K. Eckartz, C. Sartorius, L. Tercero Espinoza, M. E. Anta Espada, J. Bacher, A. Bierwirth, E. Bouyer, A. Brunot, J. Etxaniz, N. Fernqvist, G. Garcia, D. Gardner, C. Gonzalez, P. Holgersson, O. Karvan, E. Lindahl, A. Lopez, P. Menger, A. Morales Perez, F. Norefjall, N. Olivieri, E. Rietveld, B. Serrano, M. Thomten, C. Van der Eijk, D3.2 Critical Raw Materials Substitution Policies - Country Profiles, April 2015, Critical Raw Materials Innovation Network (CRM_InnoNet) project, grant agreement No 319024							
CSES_2014	Evaluation and Exchange of Good Practice for the Sustainable Supply of Raw Materials within the EU, catalogue number NB-01-14-578-EN-N					Yes		
CSES_2014A	Annex A to the previous	Yes	Yes			Yes		
Cucchiella_2015	F. Cucchiella, I. D’Adamo, S.C. L. Koh, P. Rosa, Recycling of WEEEs: An economic assessment of present and future e-waste streams, Renewable and Sustainable Energy Reviews, Volume 51, November 2015, Pages 263-272, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2015.06.010.		Yes			Yes		
Cullbrand_2012	K. Cullbrand, O. Magnusson, The Use of Potentially Critical Materials in Passenger Cars, Chalmers university of Technology, Report No. 2012:13, ISSN: 1404-8167				Yes			
DCGIS_2012	Direction générale des entreprises (2012): Outil d'analyse de la vulnérabilité des entreprises aux approvisionnements de matières critiques non énergétiques.	Yes	Yes			Yes		
DEFRA_2012	A Review of National Resource Strategies and Research, 2012	Yes	Yes			Yes		
DEFRA_2012b	Department for Environment, Food and Rural Affairs (2012a): Resource Security Action Plan: Making the most of valuable materials					Yes		

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
DeHaan_2013	P. de Haan, R. Zah: Chancen und Risiken der Elektromobilität © vdf Hochschulverlag 2013, TA-SWISS 59/2013, ISBN 978-3-7281-3488-2 / DOI 10.3218/3488-2					Yes		
DESIRE_2013	S. Giljum, L. Burrell, K. Giesecke, S. Lutter, S. Deetman, R. Kleijn, N. Eisenmenger, M. Theurl, S. Gierlinger, D3.2 Policy analysis, Development of a System of Indicators for a Resource efficient Europe (DESIRE) project, Grant agreement no: 308552	Yes	Yes				Yes	
DESIRE_2014	S. Deetman, R. Kleijn, S. Bringezu, H. Schütz, S. Pauliuk, D6.1 Indicators for critical materials, Development of a System of Indicators for a Resource efficient Europe (DESIRE) project, Grant agreement no: 308552					Yes		
Dijk_2015	K. C. van Dijk, J. Peter Lesschen, O. Oenema, Phosphorus flows and balances of the European Union Member States, Science of The Total Environment, Available online 1 October 2015, ISSN 0048-9697, http://dx.doi.org/10.1016/j.scitotenv.2015.08.048.					Yes		
DK_2011	Kingdom of Denmark Strategy for the Arctic 2011– 2020, August 2011, ISBN: 561-5				Yes			Yes
DOD_2011	Strategic and Critical Materials 2011 Report on Stockpile Requirements	Yes	Yes		Yes	Yes		Yes
DOE_2010	US: US Department of Energy, 2010, Critical materials strategy	Yes	Yes		Yes	Yes		Yes
DOE_2011	US: US Department of Energy, 2011, Critical materials strategy				Yes			
Duclos_2010_paper	Duclos, S. J.; Otto, J. P.; Konitzer, G. K.; Design in an era of constrained resources Mech. Eng.2010, 132 (9) 36– 40				Yes			
Duclos_2010_presentation	Duclos, S. General Electric (2010), Research Priorities for More Efficient Use of Critical Materials from a U.S. Corporate Perspective		Yes					
ECOFYS_2011	P. van Breevoort, R. de Vos, Rare Metals & Renewables, Commodities Now, March, 2011.					Yes		
EEA_2011	EEA, 2011, Resource efficiency in Europe, Policies and approaches in 31 EEA member and cooperating countries, EEA Report No 5/2011, ISSN 1725-9177		Yes			Yes		
EEA_2012	F. Eckermann, M. Golde, M. Herczeg, M. Mazzanti, A. Montini, R. Zoboli, Resource taxation and resource efficiency along the value chain of mineral resources, European Topic Centre on Sustainable Consumption and Production, Working Paper 3/2012, October, 2012	Yes				Yes		
EEA_2016	More from less – material resource efficiency in Europe. 2015 overview of policies, instruments and targets in 29 countries. European Environment Agency, 2016 (forthcoming)		Yes			Yes		
Elshkaki_2015	A. Elshkaki, An analysis of future platinum resources, emissions and waste streams using a system dynamic model of its intentional and non-intentional flows and stocks, Resources Policy, Volume 38, Issue 3, September 2013, Pages 241-251, ISSN 0301-4207, http://dx.doi.org/10.1016/j.resourpol.2013.04.002.				Yes	Yes		
ENTIRE_2013	Technische Universität Clausthal & Bundesanstalt für Geowissenschaften und Rohstoffe (2013): ENTIRE – Entwicklung der internationalen Diskussion zur Steigerung der Ressourceneffizienz. – 177 S., Berlin, Clausthal-Zellerfeld, Hannover.		Yes			Yes		
EP_2011	European Parliament resolution, „Effective raw materials strategy for Europe", EP, 13 September 2011.	Yes	Yes			Yes		
EP_2012	European Parliament, 2012. Substitutionability of Critical Raw Materials, IP/A/ITRE/ST/2011-15, PE 492.448 EN, October 2012	Yes	Yes			Yes		
EP_2013	G. Grieger, Trade in critical raw materials (CRMs), Main challenges		Yes			Yes		
EP_STOA_2012	European Parliament STOA, 2012. Future Metal Demand from Photovoltaic Cells and Wind Turbines. Report by the Science and Technology Options Assessment (STOA). Available at: <http://www.europarl.europa.eu/RegData/etudes/etudes/join/2011/471604/IPOL-JOIN _ET%282011%29471604_EN.pdf> (accessed September 2014).		Yes				Yes	Yes

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
EPOW_2011	Oakdene Hollins (2011) Study into the feasibility of protecting and removing critical raw materials through infrastructure development in the south east of England.	Yes	Yes					Yes
Erdmann_2011	L. Erdmann and T. E. Graedel. 2011 Criticality of Non-Fuel Minerals: A Review of Major Approaches and Analyses. Environmental Science and Technology, 45, 7620-7630.	Yes	Yes		Yes	Yes		Yes
Erdmann_2011b	L. Erdmann, S. Behrendt, Kritische Rohstoffe für Deutschland, KfW Bankengruppe, Berlin, Deutschland					Yes		
Földessy_2014	J. Földessy, Basic research of the strategic raw materials in Hungary, in the frame of the TÁMOP-4.2.2.A-11/1/KONV-2012-0005 project, ISSN: 2064-3195 ISBN: 978-615-80073-5-1							Yes
Fraunhoffer_2009	Raw materials for emerging technologies, 2009				Yes			Yes
Frenzel_2015	M. Frenzel, R. Tolosana-Delgado, J. Gutzmer, Assessing the supply potential of high-tech metals – A general method, Resources Policy, Volume 46, Part 2, December 2015, Pages 45-58, ISSN 0301-4207, http://dx.doi.org/10.1016/j.resourpol.2015.08.002.		Yes					
Frondel_2006	Frondel, M.; Grösche, D.; Huchtemann, D.; Oberheitmann, A.; Petersand, J.; Angerer, G.; Sartorius, C.; Buchholz, P.; Röhling, S.; Wagner, M. Trends der Angebots- und Nachfragesituation bei mineralischen Rohstoffen. Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), Fraunhofer-Institut für System- und Innovationsforschung (ISI), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR): Essen, Germany, 2007					Yes		
GB_2012	Geologische Bundesanstalt (2012): Der Österreichische Rohstoffplan.					Yes		
Geoscience_BRGM_2012	Braux C. & Christmann P. (2012), «Facteurs de criticité et stratégies publiques française et européenne - Enjeux et réponses», Géosciences n°15, juin, 2012 in accordance with Ad-hoc working group on defining critical raw materials (2010), Critical raw materials for the EU.				Yes			
Geoscience_Renault_2012	Enjeux technologiques des métaux et matériaux critiques. L'approche de Renault. Géosciences n°15, juin, 2012					Yes		
GEUS_2012	K. Hanghøj: The Greenland potential contribution of critical minerals to EU, Conference on Critical Minerals for the Clean Energy and High Technology Industries 2012 and beyond – the EU perspective, May 2012	Yes	Yes		Yes			
Gleich_2013	B. Gleich, B. Achzet, H. Mayer, A. Rathgeber, An empirical approach to determine specific weights of driving factors for the price of commodities—A contribution to the measurement of the economic scarcity of minerals and metals, Resources Policy, Volume 38, Issue 3, September 2013, Pages 350–362		Yes					
Gloeser_2013	S. Glöser, M. Soulier, L. A. Tercero Espinoza, M. Faulstich, Using dynamic stock & flow models for global and regional material and substance flow analysis in the field of industrial ecology. The example of a global copper flow model. 31st International Conference of the System Dynamics Society 2013. Online conference proceedings: Cambridge, Massachusetts, USA, July 21-25, 2013, ISBN: 978-1-935056-12-06, 20 pp.	Yes	Yes				Yes	
Gloeser_2015	Glöser S., Luis Tercero Espinoza, Carsten Gandenberger, Martin Faulstich. 2015. Raw material criticality in the context of classical risk assessment. Resources Policy, 44, 35-46.					Yes		
Glopolis_2012	Understanding the Raw Materials Strategies of the EU, Global and domestic perspectives, Prague Global Policy Institute – Glopolis June 2012, ISBN 978- 80-905194-9-7		Yes		Yes	Yes	Yes	Yes
Goe_2014	Goe, M., Gaustad, G., 2014. Identifying critical materials for photovoltaics in the US: a multi-metric approach. Appl. Energy 123, 387e396.							
Golev_2014	A. Golev, M. Scott, P. D. Erskine, S. H. Ali, G. R. Ballantyne, Rare earths supply chains: Current status, constraints and opportunities, Resources Policy, Volume 41, September 2014, Pages 52–59	Yes	Yes		Yes			

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Gomes_2015	J. Gomes, J. L. Pereira, I. C. Rosa, P. M. Saraiva, F. Gonçalves, R. Costa, Evaluation of candidate biocides to control the biofouling Asian clam in the drinking water treatment industry: An environmentally friendly approach, Journal of Great Lakes Research, Volume 40, Issue 2, June 2014, Pages 421-428, ISSN 0380-1330, http://dx.doi.org/10.1016/j.jglr.2014.03.013.				Yes	Yes		
Graedel_2012	T. E. Graedel, R. Barr, C. Chandler, T. Chase, J. Choi, L. Christoffersen, E. Friedlander, C. Henly, C. Jun, N. T. Nassar, D. Schechner, S. Warren, M.-Y. Yang, and C. Zhu. 2012. Methodology of Metal Criticality Determination. Environmental Science and Technology, 46, 1063-1070.							
Graedel_2015	T. E. Graedel, E. M. Harper, N. T. Nassar, and B. K. Reck, On the materials basis of modern society, PNAS May 19, 2015 vol. 112 no. 20 6295-6300 doi: 10.1073/pnas.1312752110		Yes			Yes		
Graedel_2015b	T. E. Graedel, E. M. Harper, N. T. Nassar, P. Nuss, K. Reck, Criticality of metals and metalloids. Proc. Natl. Acad. Sci. U.S.A., 10.1073/pnas.1500415112 (2015).		Yes					
Graedel_2015c	T. E. Graedel, N. T. Nassar, The criticality of metals: A perspective for geologists. Geol. Soc. London 393, 291–302 (2013).		Yes			Yes		
Gsodam_2014	P. Gsodam, M. Lassnig, A. Kreuzeder, M. Mrotzek, The Austrian silver cycle: A material flow analysis, Resources, Conservation and Recycling, Volume 88, July 2014, Pages 76-84, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2014.05.001.		Yes					
GTK_2010	Finnish Ministry of Employment and the Economy, Geological Survey of Finland (2010): Finland's Minerals Strategy					Yes		
GTK_2014	S. Kihlman, L. S. Lauri ja Mari Kivinen, Critical metals and minerals: their global production and exploration potential in Finland and the possible evolution paths of the Finnish metal mining industry in a low-carbon society, Geological Survey of Finland, Report of Investigation 213, 2014					Yes		
GTK_2015	O. Sarapää, L. S. Lauri, T. Ahtola, T. Al-Ani, S. Grönholm, N. Kärkkäinen, P. Lintinen, A. Torppa, P. Turunen, Discovery potential of hi-tech metals and critical minerals in Finland, Geological Survey of Finland, Report of Investigation 219, 2015		Yes		Yes	Yes		Yes
Guyonnet_2015	D. Guyonnet, M. Planchon, A. Rollat, V. Escalon, J. Tuduri, N. Charles, S. Vaxelaire, D. Dubois, H. Fargier, Material flow analysis applied to rare earth elements in Europe, Journal of Cleaner Production, Volume 107, 16 November 2015, Pages 215-228, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2015.04.123.					Yes		
Habib_2014	K. Habib, H. Wenzel, Exploring rare earths supply constraints for the emerging clean energy technologies and the role of recycling, Journal of Cleaner Production, Volume 84, 1 December 2014, Pages 348-359, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2014.04.035.	Yes	Yes		Yes	Yes		
Habib_2015	K. Habib, H. Wenzel, Reviewing resource criticality assessment from a dynamic and technology specific perspective – using the case of direct-drive wind turbines, Journal of Cleaner Production, Available online 18 July 2015, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2015.07.064.					Yes		
Harper_2015	Harper, E., Kavlal, G., Burmeister, M., Erbis, S., Espinoza, V., Nuss, P., Graedel, T., 2015. Criticality of the geological zinc, tin, and lead family. J. Ind. Ecol, http://dx.doi.org/10.1111/jiec.12213.	Yes	Yes			Yes		Yes
Harper_2015b	E.M. Harper, Z. Diao, S. Panousi, P. Nuss, M. J. Eckelman, T.E. Graedel, 2015, The criticality of four nuclear energy metals, Resources, Conservation and Recycling 95 (2015) 193–201. http://dx.doi.org/10.1016/j.resconrec.2014.12.009		Yes		Yes	Yes		Yes
Hatayama_2015	H. Hatayama and K. Tahara, Criticality Assessment of Metals for Japan's Resource Strategy, Materials Transactions, Vol.56 No.02 (2015) pp.229-235				Yes			Yes

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Hayes-Labruto_2013	L. Hayes-Labruto, S. J.D. Schillebeeckx, M. Workman, N. Shah, Contrasting perspectives on China's rare earths policies: Reframing the debate through a stakeholder lens, Energy Policy, Volume 63, December 2013, Pages 55-68, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2013.07.121.					Yes		
HCSS_2010	J. Kooroshy, C. Meindersma, R. Podkolinski, M. Rademaker, T. Sweijs, A. Diederen, M. Beerthuizen, S. de Goede, 'Scarcity of Minerals A strategic security issue' Report 2010 | 02, The Hague Centre for Strategic Studies (HCSS)							
HCSS_2010b	J. Kooroshy, R. Korteweg, M. de Ridder, 'Rare Earth Elements and Strategic Mineral Policy' World Foresight Forum Foundation Report 2010 | 03, The Hague Centre for Strategic Studies (HCSS) and TNO.		Yes			Yes		
Hennebel_2015	T. Hennebel, N. Boon, S. Maes, M. Lenz, Biotechnologies for critical raw material recovery from primary and secondary sources: priorities and future perspectives, New Biotechnology, Volume 32, Issue 1, 25 January 2015, Pages 121-127, ISSN 1871-6784, http://dx.doi.org/10.1016/j.nbt.2013.08.004.		Yes					
Hetzel_2014	Office parlementaire d'évaluation des choix scientifiques et technologiques: « Les enjeux stratégiques des terres rares » - Étude de faisabilité, July 2014		Yes			Yes		Yes
HoC_2011	Science and Technology Committee (STC): House of Commons Science and Technology Committee, 2011, Inquiry into strategically important metals		Yes					
Husgafvel_2013	R. Husgafvel, G. Watkins, L. Linkosalmi, O. Dahl, Review of sustainability management initiatives within Finnish forest products industry companies—Translating Eu level steering into proactive initiatives, Resources, Conservation and Recycling 76 (2013) 1– 11, http://dx.doi.org/10.1016/j.resconrec.2013.04.006				Yes			Yes
Huysman_2015	S. Huysman, S. Sala, L. Mancini, F. Ardente, R. A.F. Alvarenga, S. De Meester, F. Mathieux, J. Dewulf, Toward a systematized framework for resource efficiency indicators, Resources, Conservation and Recycling, Volume 95, February 2015, Pages 68-76, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2014.10.014.					Yes		
IDA_2010	Thomason, J. S.; Atwell, R. J.; Bajraktari, Y.; Bell, J. P.; Barnett, D. S.; Karvonides, N. S. J.; Niles, M. F.; Schwartz, E. L.; From National defence Stockpile (NDS) to Strategic Materials Security Programme (SMSP): Evidence and Analytic Support, Vol. I; Institute for defence Analyses (IDA): Alexandria, VA, 2008.		Yes			Yes		
IFRI_2010	Rare Earths and Clean Energy: Analyzing China's Upper Hand Note de l'Ifri, September 2010					Yes		
IOM3_2011	A Study of the Recycling and Recovery Infrastructure for Materials Critical to the UK, Materials Knowledge Transfer Network, June 2011					Yes		
Iparraguirre_2014	I. Iparraguirre, N. Rodriguez, F. Ibarreta, R. Martinez, J.M. Sanchez, Effect of the Cr content on the sintering behaviour of TiCN–WC–Ni–Cr3C2 powder mixtures, International Journal of Refractory Metals and Hard Materials, Volume 43, March 2014, Pages 125-131, ISSN 0263-4368, http://dx.doi.org/10.1016/j.ijrmhm.2013.11.012.				Yes		Yes	Yes
IV_2012	Industriellenvereinigung (2012): Rohstoffsicherheit 2020+. Rohstoffe für eine ressourceneffiziente Industrie.			Yes	Yes			
JOGMEG_2015	A study of a stable supply of mineral resources, Poster at the fifth EU-US-Japan Trilateral Conference on Critical Materials	Yes	Yes		Yes	Yes		Yes
JRC_2011	R.L. Moss, E. Tzimas, H. Kara, P. Willis, J. Kooroshy (2011) Critical Metals in Strategic Energy Technologies - Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies.	Yes	Yes		Yes	Yes		Yes
JRC_2013	R.L. Moss, E. Tzimas, P. Willis, J. Arendorf, L. Tercero Espinoza et al. (2013) Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector - Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies		Yes		Yes	Yes		

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JRC_2015	Dewulf, J., Mancini, L., Blengini, G.A., Sala, S., Latunussa, C. and Pennington, D. Toward an Overall Analytical Framework for the Integrated Sustainability Assessment of the Production and Supply of Raw Materials and Primary Energy Carriers. International Journal of Industrial Ecology, 2015, DOI: 10.1111/jiec.12289.			Yes				Yes
Kim_2015	J. Kim, B. Guillaume, J. Chung, Y. Hwang, Critical and precious materials consumption and requirement in wind energy system in the EU 27, Applied Energy, Volume 139, 1 February 2015, Pages 327-334, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2014.11.003.					Yes		
Knašytė_2012	M. Knašytė, I. Kliopova, J. Kazimieras Staniškis (2012): Economic Importance, Environmental and Supply Risks on Imported Resources in Lithuanian Industry. In Environmental Research, Engineering and Management 50 (2), pp. 40–47		Yes			Yes		
KNCV_2013	M.A., de Boer, K. Lammertsma, Scarcity of rare earth elements, ChemSusChem. Volume 6, Issue 11, pages 2045–2055, November 2013. doi: 10.1002/cssc.201200794.	Yes	Yes		Yes	Yes		
Knoeri_2013	C. Knoeri, P. A. Wäger, A. Stamp, H.-J. Althaus, M. Weil, Towards a dynamic assessment of raw materials criticality: Linking agent-based demand — With material flow supply modelling approaches, Science of The Total Environment, Volumes 461–462, 1 September 2013, Pages 808–812	Yes	Yes			Yes		
Leal-Ayala_2015	D. R. Leal-Ayala, J. M. Allwood, E. Petavratzi, T. J. Brown, G. Gunn, Mapping the global flow of tungsten to identify key material efficiency and supply security opportunities, Resources, Conservation and Recycling, Volume 103, October 2015, Pages 19-28, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2015.07.003.					Yes		
Loyd_2012	S. Lloyd, J. Lee, A. Clifton, L. Elghali, C. France, Recommendations for assessing materials criticality, Waste and Resource Management, Volume 165 Issue WR4, November 2012, Pages 191–200 http://dx.doi.org/10.1680/warm.12.00002					Yes		
Machacek_2014	E. Machacek, N. Fold, Alternative value chains for rare earths: The Anglo-deposit developers, Resources Policy, Volume 42, December 2014, Pages 53-64, ISSN 0301-4207, http://dx.doi.org/10.1016/j.resourpol.2014.09.003.					Yes		
Machacek_2015	E. Machacek, J. Luth Richter, K. Habib, P. Klossek, Recycling of rare earths from fluorescent lamps: Value analysis of closing-the-loop under demand and supply uncertainties, Resources, Conservation and Recycling, Volume 104, Part A, November 2015, Pages 76-93, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2015.09.005.	Yes	Yes			Yes		
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Mancini_2015a	L. Mancini, S. Sala, M. Recchioni, L. Benini, M. Goralczyk, D. Pennington, Potential of life cycle assessment for supporting the management of critical raw materials, Int J Life Cycle Assess (2015) 20:100–116 DOI 10.1007/s11367-014-0808-0		Yes			Yes		
Mancini_2015b	L. Mancini, L. Benini, S. Sala, Resource footprint of Europe: Complementarity of material flow analysis and life cycle assessment for policy support, Environmental Science & Policy, Volume 54, December 2015, Pages 367-376, ISSN 1462-9011, http://dx.doi.org/10.1016/j.envsci.2015.07.025.					Yes		
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Mayer_2015	Mayer, H. and Gleich, B. (2015) Measuring Criticality of Raw Materials: An Empirical Approach Assessing the Supply Risk Dimension of Commodity Criticality. Natural Resources, 6, 56-78. http://dx.doi.org/10.4236/nr.2015.61007		Yes					
MEECC	GREEK EXTRACTIVE INDUSTRY INTERNATIONAL ENVIRONMENT PROFILE – PROSPECTS				Yes			Yes
Merrie_2014	A. Merrie, D. C. Dunn, M. Metian, A. M. Boustany, Y. Takei, A. Oude Elferink, Y. Ota, V. Christensen, P. N. Halpin, H. Österblom, An ocean of surprises – Trends in human use, unexpected dynamics and governance challenges in areas beyond national jurisdiction, Global Environmental Change, Volume 27, July 2014, Pages 19-31, ISSN 0959-3780, http://dx.doi.org/10.1016/j.gloenvcha.2014.04.012.					Yes		
MIT_Bae_2010	J.-C. Bae, Strategies and Perspectives for Securing Rare Metals in Korea. In Critical Elements for New Energy Technologies; Proceedings of the Workshop, Boston, MA, Apr 29, 2010; An MIT Energy Initiative Workshop Report: Cambridge, MA, 2010	Yes	Yes			Yes		
Moore_2015	M. Moore, A. Gebert, M. Stoica, M. Uhlemann, W. Löser, A route for recycling Nd from Nd-Fe-B magnets using Cu melts, Journal of Alloys and Compounds, Volume 647, 25 October 2015, Pages 997-1006, ISSN 0925-8388, http://dx.doi.org/10.1016/j.jallcom.2015.05.238.		Yes			Yes		
Morf_2013	L.S. Morf, R. Gloor, O. Haag, M. Haupt, S. Skutan, F. Di Lorenzo, D. Böni, Precious metals and rare earth elements in municipal solid waste – Sources and fate in a Swiss incineration plant, Waste Management, Volume 33, Issue 3, March 2013, Pages 634-644, ISSN 0956-053X, http://dx.doi.org/10.1016/j.wasman.2012.09.010.	Yes	Yes		Yes	Yes		Yes
Moss_2013	R.L. Moss, E. Tzimas, H. Kara, P. Willis, J. Kooroshy, The potential risks from metals bottlenecks to the deployment of Strategic Energy Technologies, Energy Policy, Volume 55, April 2013, Pages 556-564, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2012.12.053.					Yes		
Nassar_2012	N. T. Nassar, R. Barr, M. Browning, Z. Diao, E. Friedlander, E. M. Harper, C. Henly, G. Kavlak, S. Kwatra, C. Jun, S. Warren, M.-Y. Yang, T. E. Graedel, Criticality of the geological copper family. Environ. Sci. Technol. 46, 1071–1078 (2012). OpenUrlCrossRefMedlineWeb of ScienceGoogle Scholar							
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Nassar_2015b	N. T. Nassar, X. Du, T. E. Graedel, Criticality of the rare earth elements. J. Ind. Ecol. 10.1111/jiec.12237 (2015).		Yes					
Nassar_2015c	N. T. Nassar, Limitations to elemental substitution as exemplified by the platinum-group metals. Green Chem. 10.1039/C4GC02197E (2015).					Yes		
NERC	SoS MinErals Science and Implementation Plan, Natural Environment Research Council		Yes			Yes		
Nicoletopoulos_2014	V. Nicoletopoulos, European Policies on Critical Raw Materials, including Rare Earths, proceedings paper of the 1st European Rare Earth Resources Conference, Milos, September 2014				Yes			
Niec_2014	M. Nieć, K. Galos, K. Szamałek, Main challenges of mineral resources policy of Poland, Resources Policy, Volume 42, December 2014, Pages 93-103, ISSN 0301-4207, http://dx.doi.org/10.1016/j.resourpol.2014.10.010.					Yes		
Nieto_2013	A. Nieto, K. Guelly, A. Kleit, Addressing criticality for rare earth elements in petroleum refining: The key supply factors approach, Resources Policy, Volume 38, Issue 4, December 2013, Pages 496-503, ISSN 0301-4207, http://dx.doi.org/10.1016/j.resourpol.2013.08.001.		Yes			Yes		

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NRC_2008	"Minerals, Critical Minerals, and the U.S. Economy", Committee on Critical Mineral Impacts of the U.S. Economy, Committee on Earth Resources, National Research Council 2008	Yes				Yes		Yes
Nuss_2014	P. Nuss, E. M. Harper, N. T. Nassar, B. K. Reck, T. E. Graedel, Criticality of iron and its principal alloying elements. Environ. Sci. Technol. 48, 4171–4177 (2014).				Yes			Yes
Oakdene_2008	Morley N., Etherly D. (2008) Material Security, Ensuring Resource Availability for the UK Economy. ISBN 978-1-906237-03-5		Yes					
Oakdene_2012	Study of By-Products of Copper, Lead, Zinc and Nickel, Rare Earth Elements Information, June 2012	Yes	Yes	Yes		Yes		Yes
Oakdene_2013	A. Chapman, et. Al., L. T. Espinoza et. Al., "Study on Critical Raw Materials at EU Level, Critical Raw Material Profiles", Oakdene Hollins, Fraunhofer ISI, December 2013.				Yes			
OECD_2011	OECD (2009) ENV/EPOC/WGWPR(2009)8/FINAL A sustainable materials management case study – Critical metals and mobile devices.				Yes			Yes
Oeko_2009	Buchert, M.; Schuler, D.; Bleher, D. Critical Metals for Future Sustainable Technologies and their Recycling Potential; Oeko-Institut; United Nations Environment Programme: Nairobi, Kenia, 2009.		Yes			Yes		
Oeko_2011	Schüler, D., Buchert, M., Liu, R., Dittrich, S., Merz, C., 2011. Study on Rare Earths and Their Recycling-Final Report for The Greens/EFA Group in the European Parliament.		Yes		Yes	Yes		Yes
Okada_2011	Okada S. & Yokoyama S. (2011): Critical Metals 2010 (Revealed China Risk) – Metal Economics Research Institute, 168, 62pp, Japan.	Yes	Yes			Yes		Yes
Ongondo_2015	F.O. Ongondo, I.D. Williams, G. Whitlock, Distinct Urban Mines: Exploiting secondary resources in unique anthropogenic spaces, Waste Management, Volume 45, November 2015, Pages 4-9, ISSN 0956-053X, http://dx.doi.org/10.1016/j.wasman.2015.05.026.					Yes		
Panousi_2015	Panousi S, et al. (2015) Criticality of seven specialty metals. J. Ind. Ecol.: in press.		Yes		Yes	Yes		Yes
PBL_2011	PBL (2011) Scarcity in a sea of plenty? Global resource scarcities and policies in the European Union and the Netherlands.	Yes	Yes			Yes		
Peck_2015	D. Peck, P. Kandachar, E. Tempelman, Critical materials from a product design perspective, Materials & Design Volume 65, January 2015, Pages 147–159		Yes			Yes		
Peiro_2013	L. T. Peiró, G. V. Méndez, R. U. Ayres, Material flow analysis of scarce metals: Sources, functions, end-uses and aspects for future supply. Environ. Sci. Technol. 47, 2939–2947 (2013).		Yes					
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PwC_2011	PwC (2011) Minerals and metals scarcity in manufacturing: the ticking timebomb.		Yes			Yes		
Ramdoo_2011	I. Ramdoo, Shopping for raw materials Should Africa be worried about EU Raw Materials Initiative? European Centre for Development Policy Management, report No. 105, February 2011					Yes		
REAP_AT_2012	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (2012b): Ressourceneffizienz Aktionsplan (REAP). Wegweiser zur Schonung natürlicher Ressourcen.	Yes	Yes		Yes	Yes		
Resnick_2011	Resnick Institute (2011), Critical materials for sustainable energy applications. California Institute of Technology.		Yes			Yes		

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RO_2012	Ministry of Economy (2012): The strategy of the mining industry 2012-2035. Strategia Industriei Miniere 2012-2035	Yes	Yes			Yes		
Roelich_2012	Roelich K (2012a) Undermining Infrastructure Briefing Note 1, Material Criticality. University of Leeds, Leeds, UK.		Yes		Yes			
Roelich_2014	K. Roelich, D. A. Dawson, P. Purnell, C. Knoeri, R. Revell, J. Busch, J. K. Steinberger. Assessing the dynamic material criticality of infrastructure transitions: A case of low carbon electricity. 2014. Applied Energy, 123, 378-386.				Yes	Yes		
SATW_2010	Schweizerische Akademie der Technischen Wissenschaften (SATW) (2010), Seltene Metalle: Rohstoffe für Zukunftstechnologien. SATW Schrift Nr. 41.	Yes	Yes		Yes	Yes		
Schaffartzik_2014	A. Schaffartzik, A. Mayer, S. Gingrich, N. Eisenmenger, C. Loy, F. Krausmann, The global metabolic transition: Regional patterns and trends of global material flows, 1950–2010, Global Environmental Change, Volume 26, May 2014, Pages 87-97, ISSN 0959-3780, http://dx.doi.org/10.1016/j.gloenvcha.2014.03.013.		Yes			Yes		
Schneider_2013	L. Schneider, M. Berger, E. Schüler-Hainsch, S. Knöfel, K. Ruhland, J. Mosig, V. Bach, M. Finkbeiner, The economic resource scarcity potential (ESP) for evaluating resource use based on life cycle assessment, The International Journal of Life Cycle Assessment, March 2014, Volume 19, Issue 3, pp 601-610		Yes			Yes		Yes
Scholz_2013	R. W. Scholz, F.W. Wellmer, Approaching a dynamic view on the availability of mineral resources: What we may learn from the case of phosphorus?, Global Environmental Change, Volume 23, Issue 1, February 2013, Pages 11-27, ISSN 0959-3780, http://dx.doi.org/10.1016/j.gloenvcha.2012.10.013.	Yes			Yes		Yes	Yes
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Seo_2013	Y. Seo, S. Morimoto, Comparison of dysprosium security strategies in Japan for 2010–2030, Resources Policy, Volume 39, March 2014, Pages 15–20	Yes			Yes	Yes		Yes
SEPA_2011	Scottish Environment Protection Agency (SEPA): AEA Technology for the Scotland and Northern Irish Forum for Environmental Research (SNIFFER), 2011, Raw materials critical to the Scottish economy				Yes			
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Thales_2013	J. Coutts, Chain Reactions, Thales Innovations, p. 10-13, November 2013		Yes	Yes	Yes	Yes	Yes	Yes
TNO_2014	T. Bastein, E. Rietveld, S. van Zyl, Materialen in de Nederlandse Economie - een beoordeling van de kwetsbaarheid, TNO report R10686, mei 2014.					Yes		
TRANSLATLANTIC_2011	S.-A. Mildner, Securing Access to Critical Raw Materials: What Role for the WTO in Tackling Export Restrictions? Four Proposals for a Transatlantic Agenda, Transatlantic Academy, December 2011		Yes				Yes	
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UKERC_2011	R. Gross, J. Speirs, C. Candelise, B. Gross, Materials Availability: Potential constraints to the future low-carbon economy - Working Paper I: Thin Film photovoltaics, 2011						Yes	
UKERC_2013	R. Gross, J. Speirs, B. Gross, Y. Houari, Energy Materials Availability Handbook, 2013	Yes	Yes				Yes	
UKERC_2013c	R. Gross, J. Speirs, Y. Houari, Materials Availability: Comparison of material criticality studies - methodologies and results - Working Paper III, 2013		Yes				Yes	
UKERC_2014	R. Gross, J. Speirs, M. Contestabile, C. Candelise, B. Gross, Yassine Houari, Materials Availability for Low Carbon Technologies, 2014					Yes		
UNCTAD_2014	Commodities at a Glance: Special Issue on Rare Earths, N°5 - May 2014, UNCTAD/SUC/2014/1				Yes			Yes
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Vesborg_2012	P. C. K. Vesborg, T. F. Jaramillo, Addressing the terawatt challenge: Scalability in the supply of chemical elements for renewable energy. RSC Adv. 2, 7933–7947 (2012).				Yes			
Viebahn_2015	P. Viebahn, O. Soukup, S. Samadi, J. Teubler, K. Wiesen, M. Ritthoff, Assessing the need for critical minerals to shift the German energy system towards a high proportion of renewables, Renewable and Sustainable Energy Reviews, Volume 49, September 2015, Pages 655-671, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2015.04.070.					Yes		
VW_2009	Rosenau-Tornow, D.; Buchholz, P.; Riemann, A.; Wagner, M. Assessing the long-term supply risks for mineral raw materials – A combined evaluation of past and future trends Resour. Policy2009, 34 (4) 161–175							Yes
Wakolbinger_2014	T. Wakolbinger, F. Toyasaki, T. Nowak, A. Nagurney, When and for whom would e-waste be a treasure trove? Insights from a network equilibrium model of e-waste flows, International Journal of Production Economics, Volume 154, August 2014, Pages 263-273, ISSN 0925-5273, http://dx.doi.org/10.1016/j.ijpe.2014.04.025.					Yes		
Wall_2012	F. Wall, Don't stop using rare earths, Materials Today, Volume 15, Issue 4, April 2012, Page 134, ISSN 1369-7021, http://dx.doi.org/10.1016/S1369-7021(12)70058-5.		Yes			Yes		
Watanabe_2011	Watanabe, Y. 2011. "Japanese Approach Toward Critical Materials". Power-Point presentation from Keynote Address at Critical Materials for Sustainable Energy Applications Workshop. Pasadena, CA: Caltech. 14 April 2011.		Yes					

Short reference	Reference	Literature review?	Referencing EC methodology?	Applying EC methodology?	Developing methodology?	Referencing EC list?	Using EC list?	Developing own list?
Watkins_2013	G. Watkins, R. Husgafvel, N. Pajunen, O. Dahl, K. Heiskanen, Overcoming institutional barriers in the development of novel process industry residue based symbiosis products – Case study at the EU level, Minerals Engineering, Volume 41, February 2013, Pages 31-40, ISSN 0892-6875, http://dx.doi.org/10.1016/j.mineng.2012.10.003.		Yes					
Weiser_2015	A. Weiser, D. J. Lang, T. Schomerus, A. Stamp, Understanding the modes of use and availability of critical metals – An expert-based scenario analysis for the case of indium, Journal of Cleaner Production, Volume 94, 1 May 2015, Pages 376-393, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2015.01.079.		Yes					
Wubbeke_2013	J. Wübbeke, Rare earth elements in China: Policies and narratives of reinventing an industry, Resources Policy 38 (2013) 384–394, http://dx.doi.org/10.1016/j.resourpol.2013.05.005	Yes	Yes		Yes	Yes		Yes
WWF_2014	WWF, 2014. Critical materials for the transition to a 100% sustainable energy future, WWF International, Gland, Switzerland. ISBN 978-2-940443-74-1.					Yes		
Ziemann_2012	S. Ziemann, M. Weil, L. Schebek, Tracing the fate of lithium––The development of a material flow model, Resources, Conservation and Recycling, Volume 63, June 2012, Pages 26-34, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2012.04.002.	Yes	Yes					
Zimmerman_2013	T. Zimmermann, Historic and future flows of critical materials resulting from deployment of photovoltaics, proceedings of the 6th International Conference on Life Cycle Management in Gothenburg 2013.		Yes					
Zuser_2011	A. Zuser, H. Rechberger, Considerations of resource availability in technology development strategies: The case study of photovoltaics, Resources, Conservation and Recycling 56 (2011) 56–65		Yes					

4 ANNEX D: SUBSTITUTION IN VARIOUS CRITICALITY STUDIES

4.1 Overview of recent criticality studies and their approach to assess substitution.

Methodology	Materials	Details
CRM InnoNet (CRM_InnoNet)	Antimony, Beryllium, Cobalt, Fluorspar, Gallium, Germanium, Graphite, Indium, Magnesium, Niobium, PGMs, REEs, Tantalum and Tungsten.	The materials substitutability is evaluated qualitatively and presented via colour codes: from **Red = not substitutable to Green = completely and easily substitutable at no additional cost**
"Materials critical to the energy industry" – Univ. of Augsburg (Achzet et al. 2011)	Chromium, Cobalt, Copper, Gallium, Germanium, Indium, Lithium, Molybdenum, Phosphorus, Platinum, Potash, REE, Rhodium, Silver, Tellurium, Tungsten, Vanadium.	To determine Substitutability performance, availability, cost and environmental concerns are taken into consideration. The evaluation is qualitative. Estimates "H", "M" and "L" are assigned for the investigated materials, namely: **"H" – no substitute on materials level available OR substitute available but itself considered critical** **"M" – Substitute available with degradation in performance OR no substitute available on materials level but on systemic level (e.g. wind turbine without REEs)** **"L" – Substitute available**
National Research Council (NRC 2008)	Copper, Gallium, Indium, Lithium, Manganese, Niobium, Platinum-group PGMs, REs, Tantalum, Titanium, and Vanadium.	Substitutability is taken into account for both axes in the methodology: "Supply Risk" & "Impact of Supply risk" as following: - 33 % of the "Impact" component, i.e. materials for which substitutes are easily found is going to be of slightly less 'importance' than one for which substitutes that provide the same properties, at comparable costs, cannot be found in the short term. - 20 % of the "Supply risk" component.
Oakdene Hollins (Morley and Eatherley 2008)	69 Materials studied.	Methodology: matrix type including 8 indicators grouped under two main categories: "Supply Risk" & "Material risk". Substitutability is an indicator within the "Material Risk". Evaluation: **Qualitative - scores of 1 (high substitutability) to 3 (low substitutability) are given for each material.** The scoring was based on various sources. Where data were not available for a particular material a score of 2 was given.
Volkswagen AG & BGR (Rosenau-Tornow et al. 2009)	-	The 'Substitution' indicator here is a part of the 'Growth in demand' together with: analysis of new technologies influencing growth in demand, GDP, industrial production, population or migration into cities, regulatory or other public policy changes etc. Methodology: matrix type including 10 indicators. Evaluation**: Qualitative – scores from 1 to 9 are given: Relaxed (1-3); Moderate (4-6) and Problematic (7-9).**
US DoE (USDOE 2010, 2011)	Dysprosium, Europium, Neodymium, Terbium, Yttrium, Cerium, Indium, Lanthanum, Tellurium, Cobalt, Gallium, Lithium, Manganese, Nickel, Praseodymium, Samarium.	Methodology: 2 axis – "Supply risk" vs "Importance to clean energy". 'Substitutability limitations' – weighted as 25% of the "Importance" component (Impact). Evaluation: **Qualitative - scoring for short- and medium-term criticality as following: 1 (least critical) to 4 (most critical).**
General Electric (Duclos 2010; GE 2010)	33 Materials assessed in the 2008 methodology and 53 in the 2012 edition.	Methodology: 2 axis – "Supply and Price Risk" vs "Impact". 'Substitutability' for specific applications is 25 % of the "Impact" component and 1/6 of the "Supply risk" component.

Methodology	Materials	Details
		The "Substitutability" context is considered on the level of Materials as well as system substitution potential: **qualitative assessment.**
Yale (Graedel et al. 2012, 2015)	62 metals and metalloids evaluated.	Methodology: 3D “criticality space” consisting of "Supply risk", "Environmental implications", and "Vulnerability to supply restriction". 'Substitutability' indicator is 1/3 of the "Vulnerability to Supply Restriction" axis, divided equally between 4 sub-indicators: - Substitute Performance - Substitute Availability - Environmental impact & - Net import reliance ratio **Semi-analytical approach adopted.**
(AEA Technology 2010) (Review of the Future Resource Risks Faced by UK Business and an Assessment of Future Viability)	-	The 'Substitutability' indicator is called 'Availability of alternatives'. This criterion considers whether alternatives for a given resource are available or not. **Quantitative evaluation** is performed based on the following scoring: **- High: Mo materials available** **- Medium: Limited alternatives or potential alternative not fully developed yet** **- Low: Yes alternatives available**
(BGS 2012)	52 materials studied in the 2011 edition and 41 materials in the 2012 edition.	The 'Substitutability' indicator is only 1/7 part of the "Supply Risk" component. Substitutability scoring: **qualitative** **1 = Low** **2 = Medium** **3 = High**

4.2 References

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AEA Technology. 2010. *Review of the Future Resource Risks Faced by Business and an Assessment of Future Viability*. Final Report to the Department for Environment, Food and Rural Affairs. London.

BGS. 2012. *Risk list 2012: An updated supply risk index for chemical elements or element groups which are of economic value*. Nottingham, United Kingdom: British Geological Survey.

CRM_InnoNet. CRM InnoNet: Substitution of Critical Raw Materials, FP7 Project. http://www.criticalrawmaterials.eu/. Accessed February 24, 2016.

Duclos, S.J.O., Jeffrey P. Konitzer. Douglas G. 2010. Design in an Era of Constrained Resources. *Mechanical Engineering* 132(9): 36–40.

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Graedel, T.E., R. Barr, C. Chandler, T. Chase, J. Choi, L. Christoffersen, E. Friedlander, et al. 2012. Methodology of Metal Criticality Determination. *Environmental Science & Technology* 46(2): 1063–1070.

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http://www.oakdenehollins.co.uk/pdf/material_security.pdf. Accessed September 17, 2013.

NRC. 2008. *Minerals, Critical Minerals, and the U.S. Economy*. Committee on Critical Mineral Impacts of the U.S. Economy, Committee on Earth Resources, National Research Council. Washington, D.C.: The National Academies Press.

Rosenau-Tornow, D., P. Buchholz, A. Riemann, and M. Wagner. 2009. Assessing the long-term supply risks for mineral raw materials—a combined evaluation of past and future trends. *Resources Policy* 34(4): 161–175.

USDOE. 2010. *Critical Materials Strategy*. U.S. Department of Energy. http://energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf. Accessed September 11, 2012.

USDOE. 2011. *Critical Materials Strategy*. U.S. Department of Energy (USDOE). http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf. Accessed February 25, 2016.

5 ANNEX E (WORKED EXAMPLES)

5.1 Worked examples for Lithium, Indium and Tungsten

Methodological note:

- The objective of the simulations presented in this Annex is to test the impact of all the methodological changes on concrete cases;
- Simulations are run using data for the year 2010 extracted from the 2014 CRM report;
- The revised methodology was applied for all aspects except for the calculation of the final scores of the supply risk and economic importance;

Calculation flow for Lithium's economic importance

Application / Primary use	Share (%)	2-digit NACE sector	VA (mil.Euro, 2013)	Share * VA
Ceramics and glass	20%	23, Manufacture of other non-metallic mineral products	59,314.10	11,862.82
Batteries	40%	27, Manufacture of electrical equipment	84,856.30	33,942.52
Lubricating grease	13%	20, Manufacture of chemicals and chemical products	109,753.20	14,267.92
Continuous casting	7%	24, Manufacture of basic metals	57,152.20	4,000.65
Gas and air treatment	4%	28, Manufacture of machinery and equipment n.e.c.	191,750.10	7,670.00
Synthetic rubbers and plastics	3%	20, Manufacture of chemicals and chemical products	109,753.20	3,292.59
Aluminium smelting	1%	24, Manufacture of basic metals	57,152.20	571.52
Pharmaceuticals	3%	21, Manufacture of basic pharmaceutical products and pharmaceutical preparations)	81,211.40	2,436.34
Other	9%	NA	NA	NA
Total	**100%**			**78,044.37**
Li SI_{EI}				**0.92**
Lithium score, unscaled = 78044.37 * 0.92 =				**71,800.82**
EI_{max} (provisional value)				**191,750.10**
Lithium score, scaled (provisional) = 71800.82/191750.10				**0.3744**
EI (provisional) = 0.3744 * 10				**3.744**

Detailed allocation of Lithium end uses to the corresponding NACE sectors and CPA categories

Application / Primary use	Share	2-digit NACE REV. 2 sector	Detailed NACE REV.2 sector (3- and 4-digit)	Corresponding CPA categories
Ceramics and glass	20%	23, Manufacture of other non-metallic mineral products	23.10, Manufacture of glass and glass products 23.40, Manufacture of other porcelain and ceramic products 23.41, Manufacture of ceramic household and ornamental articles	23.31.10, Ceramic tiles and flags
Batteries	40%	27, Manufacture of electrical equipment	27.2, Manufacture of batteries and accumulators	27.20.11, Primary cells and primary batteries 27.20.23, Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators
Lubricating grease	13%	20, Manufacture of chemicals and chemical products	20.59, Manufacture of other chemical products n.e.c.	20.59.41, Lubricating preparations
Continuous casting	7%	24, Manufacture of basic metals	24.5, Casting of metals	to be identified
Gas and air treatment	4%	28, Manufacture of machinery and equipment n.e.c.	28.25, Manufacture of non-domestic cooling and ventilation equipment	28.25.30, Parts of refrigeration and freezing equipment and heat pumps 28.25.14 : Machinery and apparatus for filtering or purifying gases n.e.c.
Synthetic rubbers and plastics	3%	20, Manufacture of chemicals and chemical products	20.1, Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	20.17.10, Synthetic rubber in primary forms
Aluminium smelting	1%	24, Manufacture of basic metals	24.42, Aluminium production	24.42.11, Aluminium, unwrought
Pharmaceuticals	3%	21, Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.1, Manufacture of basic pharmaceutical products	to be identified
Other	9%	NA	NA	NA

Calculation flow for Indium's economic importance

Application / primary use	Share	2-digit NACE sector	VA (2012)	Share * VA
Flat panel displays	70%	26, Manufacture of computer, electronic and optical products	73,811.30	51,667.91
Opto-electronic windows	9%	27, Manufacture of electrical equipment	85,211.40	7,669.03
Semiconductors	4%	26, Manufacture of computer, electronic and optical products	73,811.30	2,952.45
Solar components	8%	26, Manufacture of computer, electronic and optical products	73,811.30	5,904.90
Low melting point alloys	9%	24, Manufacture of basic metals	60,000.00	5,400.00
Total	**100%**			**73,594.29**
In SI_{EI}				**0.95**
In score, unscaled = 73594.29 * 0.95 =				**69,914.57**
EI_{max} (provisional value)				**191,750.10**
In score, scaled (provisional) = 69914.57 / 191750.10				**0.3646**
EI In (provisional) = 0.3646 * 10				**3.646**

Detailed allocation of Indium's end uses to the corresponding NACE sectors and CPA categories

End use/Application	Share	2-digit NACE REV. 2 sector	Detailed NACE REV.2 sector (3- and 4-digit)	Corresponding CPA categories
Flat panel displays	70%	26, Manufacture of computer, electronic and optical products	26.40, Manufacture of consumer electronics; 26.20, Manufacture of computers and peripheral equipment	26.40.34, Monitors and projectors, not incorporating television reception apparatus and not principally used in an automatic data processing system; 26.20.17, Monitors and projectors, principally used in an automatic data processing system
Opto-electronic windows	9%	27, Manufacture of electrical equipment	27.90, Manufacture of other electrical equipment	27.90.20, Indicator panels with liquid crystal devices or light-emitting diodes; electric sound or visual signalling apparatus
Semiconductors	4%	26, Manufacture of computer, electronic and optical products	26.11, Manufacture of electronic components	26.11.22, Semiconductor devices; light-emitting diodes; mounted piezo-electric crystals; parts thereof
Solar components	8%	26, Manufacture of computer, electronic and optical products	26.11, Manufacture of electronic components	26.11.22, Semiconductor devices; light-emitting diodes; mounted piezo-electric crystals; parts thereof
Low melting point alloys	9%	24, Manufacture of basic metals	24.45, Other non-ferrous metal production	24.45.30, Other non-ferrous metals and articles thereof: cermets; ash and residues, containing metals or metallic compounds

Calculation flow for Tungsten's economic importance

Application / Primary use	Share	2-digit NACE sector	VA (2012)	Share * VA
Cemented carbides (hardmetals)	60%	20, Manufacture of chemicals and chemical products	109,753.20	65,851.92
Ttool/high speed steels	13%	24, Manufacture of basic metals	60,000.00	7,800.00
Super-alloys	6%	24, Manufacture of basic metals	60,000.00	3,600.00
Mill products	10%	24, Manufacture of basic metals	60,000.00	6,000.00
Lighting	4%	27, Manufacture of electrical equipment	85,211.40	3,408.46
Chemistry and others	7%	20, Manufacture of chemicals and chemical products	109,753.20	7,682.72
Total	**100%**			**94,343.10**
W SI_{EI}				**0.91**
W EI score, unscaled = 94343.1 * 0.91 =				**85,852.22**
EI_{max} (provisional value)				**191,750.10**
W score, scaled (provisional) = 85852.22 /191750.10				**0.447**
EI In (provisional) = 0.4477 * 10				**4.477**

Detailed allocation of Tungsten's end uses to the corresponding NACE sectors and CPA categories

Applications / Primary uses	Share	2-digit NACE REV. 2 sector	Detailed NACE REV.2 sector (3- and 4-digit)	Corresponding CPA categories	PRODCOM
Cemented carbides (hardmetals)	60%	20, Manufacture of chemicals and chemical products	20.59, Manufacture of other chemical products n.e.c.	20.59.57, Prepared binders for foundry moulds or cores; chemical products	20.59.57.40, Non-agglomerated metal carbides mixed together or with metallic binders
Ttool/high speed steels	13%	24, Manufacture of basic metals	24.10, Manufacture of basic iron and steel and of ferro-alloys	to be identified	to be identified
Super-alloys	6%	24, Manufacture of basic metals	24.10, Manufacture of basic iron and steel and of ferro-alloys	24.10.12, Ferro-alloys	24.10.12.90, Other ferro alloys n.e.c.
Mill products	10%	24, Manufacture of basic metals	24.4, Manufacture of basic precious and other non-ferrous metals 24.45, Other non-ferrous metal production	24.45.30, Other non-ferrous metals and articles thereof: cermets; ash and residues, containing metals or metallic compounds	24.45.30.13, Tungsten (wolfram) and articles thereof (excluding waste and scrap), n.e.c.
Lighting	4%	27, Manufacture of electrical equipment	27.40, Manufacture of electric lighting equipment	27.40.12, Tungsten halogen filament lamps, excluding ultraviolet or infra-red lamps	27.40.12.50, Tungsten halogen filament lamps for motorcycles and motor 8539 21 30 vehicles (excluding ultraviolet and infrared lamps) 27.40.12.93; 27.40.12.95
Chemistry and others	7%	20, Manufacture of chemicals and chemical products	20.12, Manufacture of dyes and pigments 20.13, Manufacture of other inorganic basic chemicals 20.59, Manufacture of other chemical products n.e.c.	20.12.19, Other metal oxides, peroxides and hydroxides 20.13.51, Salts of oxometallic or peroxometallic acids; colloidal precious metals 20.59.41, Lubricating preparations	20.12.19.90, Other inorganic bases; other metal oxides, hydroxides and peroxides, n.e.c. 20.13.51.10, Manganites, manganates and permanganates; molybdates; tungstates (wolframates)

Existing substitutes for the main end-use applications of Lithium

End-use application	Substitute material	Associated patents	Patent's Applicant	Additional info
Batteries	Aluminium	CN103825045 (A) — 2014-05-28: Aluminium ion battery and preparation method thereof;	UNIV BEIJING SCIENCE & TECH	http://machinedesign.com/news/goodbye-lithium-ion-batteries
	Aluminium	CN104078678 (A) — 2014-10-01 : Sulfur-carbon conductive polymer positive electrode and secondary aluminium battery using same	NANJING ZHONGCHU NEW ENERGY CO LTD	
	Sodium	CN104610569 (A) — 2015-05-13: Novel sodium-sulfur battery and preparation method of separator of battery	UNIV ZHEJIANG	http://www.extremetech.com/electronics/149779-sodium-air-batteries-could-replace-lithium-air-as-the-battery-of-the-future
	Sodium	US2015303467 (A1) — 2015-10-22 : ANODE COMPOSITIONS FOR SODIUM-ION BATTERIES AND METHODS OF MAKING SAME	3M INNOVATIVE PROPERTIES CO [US]	http://www.reliableplant.com/Read/26973/Alternative-to-lithium-ion-batteries http://cen.acs.org/articles/93/i29/Challenging-Lithium-Ion-Batteries-New.html
	Nickel			NiZn; NiCd or NiMH; http://www.toolcrib.com/blog/2007/03/making-the-power-tool-battery-decision-nimh-vs-nicad-vs-li-ion http://www.thehybridshop.com/media/blogs/nickel-metal-hydride-vs-lithium-best-hybrid-battery/
	Zinc	US2015303530 (A1) — 2015-10-22 : METHOD FOR CHARGING A ZINC-AIR BATTERY WITH LIMITED POTENTIAL	ELECTRICITE DE FRANCE [FR]	Zinc–air batteries http://cleantechnica.com/2013/05/30/new-zinc-air-battery-could-pack-twice-the-power-of-lithium-ion/ http://www.eosenergystorage.com/technology/ http://www.bloomberg.com/news/articles/2013-05-01/con-edison-to-test-power-grid-battery-with-eos-in-new-york-city
	Lead			http://www.powertechsystems.eu/home/tech-corner/lithium-ion-vs-lead-acid-battery/
Glass and ceramics	Sodium			http://www.essentialchemicalindustry.org/chemicals/sodium-carbonate.html
	Calcium	CA 2446421 A1: Method for reducing the amount of lithium in glass production	Specialty Minerals (Michigan) Inc., John Albert Hockman	Dictionary of Glass: Materials and Techniques; ISBN 0-8122-3619-X

End-use application	Substitute material	Associated patents	Patent's Applicant	Additional info
Glass and ceramics	Magnesium	US 6531421 B2: Method of reducing the amount of lithium in glass production	Specialty Minerals (Michigan) Inc.	Dictionary of Glass: Materials and Techniques; ISBN 0-8122-3619-X
	Silicon	CA 2446421 A1: Method for reducing the amount of lithium in glass production	Specialty Minerals (Michigan) Inc., John Albert Hockman	
	Potassium			http://chemwiki.ucdavis.edu/Inorganic_Chemistry/Descriptive_Chemistry/Elements_Organized_by_Block/1_s-Block_Elements/Group__1%3A_The_Alkali_Metals/Chemistry_of_Potassium
Lubricates	Sodium			http://www.reliabilityweb.com/art04/understanding_grease.htm
	Aluminium			Lubricating Greases - manufacturing technologies, ISBN 81-224-1668-3
	Barium			http://www.reliabilityweb.com/art04/understanding_grease.htm
	Calcium			http://www.reliabilityweb.com/art04/understanding_grease.htm
Gas & air treatment	Sodium			http://www.rockwoodlithium.com/applications/air-conditioners-gas-and-air-treatment/
	Potassium			http://www.allergyconsumerreview.com/airpurifiers-information.html#sthash.SQd3Rij2.dpbs
	Magnesium			http://www.alibaba.com/magnesium-and-aluminium-air-filter-cover-suppliers.html
	Aluminium			http://www.allergyconsumerreview.com/airpurifiers-information.html#sthash.SQd3Rij2.dpbs
	Carbon (Active carbon)			http://www.airfilterusa.com/commercial-industrial/carbon-filters
	Silver			http://learn.livingdirect.com/portable-air-conditioner-filters/

End-use application	Substitute material	Associated patents	Patent's Applicant	Additional info
Continuous casting	Magnesium	RU2012150908 (A): STEEL HIGH-MAGNESIA FLUX AND METHOD OF ITS PRODUCTION (VERSIONS)	OTKRYTOE AKTSIONERNOE OBSHCHESTVO "URAL'SKIJ INSTITUT METALLOV"; OBSHCHESTVO S OGRANICHENNOJ OTVETSTVENNOST'JU EHTIPRODAKTS	
	Sodium			Industrial minerals & rocks: 7th edition, Society for mining, Metallurgy, and Exploration, Inc. (SME)
	Potassium			Industrial minerals & rocks: 7th edition, Society for mining, Metallurgy, and Exploration, Inc. (SME)
Synthetic rubbers & plastics	Magnesium			http://www.mannekus.com/industrial/
	Sodium			Basic principles in Applied Catalysis, M. Baerns (Ed.), ISSN 0172-6218
Pharmaceuticals	No substitute			
Aluminium smelting	Potassium	US 5505823 A: Method for the electrolytic production of aluminum	Solv-Ex Corporation	https://www.alcoa.com/global/en/about_alcoa/pdf/Smeltingpaper.pdf http://www.aluminum-production.com/aluminum_history.html
	Sodium			http://www.istc.illinois.edu/info/library_docs/manuals/primmetals/chapter4.htm http://chemistry.elmhurst.edu/vchembook/327aluminum.html

SCP assessments for the identified substitutes for Lithium

End-use application	Shares of main material in end-use application	Sub-shares of substitutes in end-use application	Substitute material	Substitute Performance (SP)	Substitute Cost (SC)	SCP (matrix evaluation)
Batteries	40%*	6%	Aluminium	Similar	Lower	0.7
		5%	Nickel	Reduced	Lower	0.8
		6%	Zinc	Similar	Lower	0.7
		28%	Lead	Reduced	Lower	0.8
		15%	Sodium	Reduced	Lower	0.8
		40%	Lithium	No substitute	No substitute	1
Glass & ceramics	20%	10%	Sodium	Reduced	Lower	0.8
		10%	Calcium	Reduced	Lower	0.8
		10%	Magnesium	Reduced	Lower	0.8
		10%	Silicon	Reduced	Higher (5 times)	1
		10%	Potassium	Reduced	Lower	0.8
		50%	Lithium	No substitute	No substitute	1
Lubricates*	13%	7%	Sodium	Reduced	Lower	0.8
		5%	Aluminium	Reduced	Lower	0.8
		5%	Barium	Reduced	Lower	0.8
		8%	Calcium	Reduced	Lower	0.8
		75%	Lithium	No substitute	No substitute	1
Gas & air treatment	4%	9%	Sodium	Reduced	Lower	0.8
		8%	Potassium	Reduced	Lower	0.8
		8%	Magnesium	Reduced	Lower	0.8
		8%	Aluminium	Reduced	Lower	0.8
		9%	Carbon (active)	Reduced	Lower	0.8
		8%	Silver	Reduced	Higher (5 times)	1
		50%	Lithium	No substitute	No substitute	1
Continuous casting	7%	10%	Magnesium	Reduced	Lower	0.8
		10%	Potassium	Reduced	Lower	0.8
		10%	Sodium	Reduced	Lower	0.8
		70%	Lithium	No substitute	No substitute	1
Synthetic rubbers & plastics	3%	15%	Magnesium	Reduced	Lower	0.8
		15%	Sodium	Reduced	Lower	0.8
		70%	Lithium	No substitute	No substitute	1
Pharmaceuticals	3%	100%	No substitute: Lithium	No substitute	No substitute	1
Aluminium smelting	1%	30%	Sodium	Reduced	Lower	0.8
		20%	Potassium	Reduced	Lower	0.8
		50%	Lithium	No substitute	No substitute	1
Other	9%	100%	Lithium	No substitute	No substitute	1

* *Detailed sub-shares:* http://www.galaxylithium.com/media/presentations/20150413-gxy-presentation.pdf

SP, SCr and SCo sub-parameters for Lithium

End-use application	Shares of main material in end-use application	Sub-shares of substitutes within end-use application	Substitute material	Substitute Production (SP)	Substitute Criticality (SCr)	Substitute Co-production (SCo)
Batteries	40%	6%	Aluminium	0.8	0.8	0.8
		5%	Nickel	0.8	0.8	0.8
		6%	Zinc	0.8	0.8	0.8
		28%	Lead	0.8	0.8	0.8
		15%	Sodium	0.8	0.8	0.8
		40%	Lithium	1	1	1
Glass & ceramics	20%	10%	Sodium	0.8	0.8	0.8
		10%	Calcium	0.8	0.8	0.8
		10%	Magnesium	0.8	1	0.8
		10%	Silicon	0.8	1	0.8
		10%	Potassium	0.8	0.8	0.8
		50%	Lithium	1	1	1
Lubricates	13%	7%	Sodium	0.8	0.8	0.8
		5%	Aluminium	0.8	0.8	0.8
		5%	Barium	1	0.8	0.8
		8%	Calcium	0.8	0.8	0.8
		75%	Lithium	1	1	1
Gas & air treatment	4%	9%	Sodium	0.8	0.8	0.8
		8%	Potassium	0.8	0.8	0.8
		8%	Magnesium	0.8	1	0.8
		8%	Aluminium	0.8	0.8	0.8
		9%	Carbon (active)	0.8	0.8	0.8
		8%	Silver	0.8	0.8	0.8
		50%	Lithium	1	1	1
Continuous casting	7%	10%	Magnesium	0.8	1	0.8
		10%	Potassium	0.8	0.8	0.8
		10%	Sodium	0.8	0.8	0.8
		70%	Lithium	1	1	1
Synthetic rubbers & plastics	3%	15%	Magnesium	0.8	1	0.8
		15%	Sodium	0.8	0.8	0.8
		70%	Lithium	1	1	1
Pharmaceuticals	3%	100%	No substitute: Lithium	1	0.8	0.8
Aluminium smelting	1%	30%	Sodium	0.8	0.8	0.8
		20%	Potassium	0.8	0.8	0.8
		50%	Lithium	1	1	1
Other	9%	100%	Lithium	1	1	1

Existing substitutes for the main end-use applications of Indium

End-use application	Substitute material	Associated patents	Patent's Applicant	Additional info
Flat panel displays (liquid crystal displays; plasma-display panels; touch screens; monitors etc.)	**Tin** (Fluorine doped Tin Oxide - FTO)	CN104451610 (A): Preparation method for fluorine-doped tin oxide transparent conductive thin film	UNIV LIAONING	Manufacturers: SIGMA ALDRICH; HONGKONG ZEELANG GLASS LIMITED; Lianyungang Fenqiang Trading Co., Ltd.
	Zinc (Aluminium doped Zinc Oxide - AZO)	GB2512069 (A): Aluminium doped tin oxide coatings	PILKINGTON GROUP LTD [GB]	Manufacturers: SIGMA ALDRICH; American elements - the materials science manufacturer; US Research Nanomaterials, Inc: The advanced Nanomaterials Provider.
	Zinc (Aluminium doped Zinc Oxide - AZO)	FR2998582 (A1): Use of a composition comprising diethylzinc and tricyclic aryl compound, in chemical vapor deposition process for depositing zinc oxide film, such as conductive transparent oxide film, which is useful to manufacture flat panel display.	AIR LIQUIDE [FR]	Manufacturers: SIGMA ALDRICH; American elements - the materials science manufacturer; US Research Nanomaterials, Inc: The advanced Nanomaterials Provider.
Opto-electronic windows (architectural glass /smart windows/windscreens etc.)	**Tin** (Fluorine doped Tin Oxide - FTO)	No patents found for this particular application.		Manufacturers: SIGMA ALDRICH; HONGKONG ZEELANG GLASS LIMITED; Lianyungang Fenqiang Trading Co., Ltd.
	Zinc (Aluminium doped Zinc Oxide - AZO)	No patents found particularly for this particular application.		Manufacturers: SIGMA ALDRICH; American elements - the materials science manufacturer; US Research Nanomaterials, Inc: The advanced Nanomaterials Provider;
Semiconductors	**Gallium** (GaAs; GaN; AlGaN)	CN104600565 (A) : Gallium arsenide laser with low electronic leakage and manufacturing method thereof	INST SEMICONDUCTORS CAS	Manufacturers: AXT Inc; Kyma Technologies; CrystAl-N; Freiberger Compound Materials;
	Gallium (GaAs; GaN; AlGaN)	CN104393132 (A) : Green-light LED (Light Emitting Diode) epitaxial layer structure and growing method	INST SEMICONDUCTORS CAS	Manufacturers: AXT Inc; Kyma Technologies; CrystAl-N; Freiberger Compound Materials;
	Germanium (SiGe)	CN104141169 (A) : Germanium silicon epitaxial growth reaction chamber, germanium silicon epitaxial growth method and semiconductor manufacture device	SEMICONDUCTOR MFG INT CORP	Manufacturers: SWI; PAM-XIAMEN

End-use application	Substitute material	Associated patents	Patent's Applicant	Additional info
Semiconductors	**Germanium** (SiGe)	CN104037275 (A): Silicon nitride membrane strained germanium LED device with suspension structure and production method of silicon nitride membrane strained germanium LED device.	UNIV XIDIAN	Manufacturers: SWI; PAM-XIAMEN
Solar components	**Silicon**			Using the established technology is currently available as a substitution alternative, thus Si to be considered as substitute; although with limitations - not applicable in all applications.
	Zinc	WO2014134515 (A1): HIGH-EFFICIENCY, LOW-COST SILICON-ZINC OXIDE HETEROJUNCTION SOLAR CELLS	UNIV LELAND STANFORD JUNIOR [US]; HONDA PATENTS & TECH NORTH AM [US]	
	Zinc	CN103803809 (A): Method for producing zinc oxide-based transparent conductive coating glass	BENGBU GLASS IND DESIGN INST; CHINA TRIUMPH INT ENG CO LTD	
	Zinc	CN102664198 (A) : Broad-spectrum light trapping zinc oxide transparent conductive film and preparation method thereof	UNIV NANKAI	
Low melting point alloys (soldering)	**Tin**	CN104384746 (A) : Low-melting-point lead-free soldering tin particles and preparation method thereof	MINGGUANG XUSHENG TECHNOLOGY CO LTD	Applicable only for limited cases, depending on temperature diapason. For very low temperatures only Indium is feasible solution.

SCP assessments for the identified substitutes for Indium

End-use application	Share of main material in end-use applica-tion	Sub-shares of substitutes within end-use application	Substitute material	Substi-tute Perfor-mance (SP)	Substitute Cost (SC)	SCP (matrix evaluation)
Flat panel displays	70 %	5%	Tin	Reduced	Lower	0.8
		5%	Zinc	Reduced	Lower	0.8
		90%	Indium	No substitute	No substitute	1
Opto-electronic windows	9 %	25%	Tin	Similar	Lower	0.7
		25%	Zinc	Similar	Lower	0.7
		50%	Indium	No substitute	No substitute	1
Semiconductors	4 %	25%	Gallium	Similar	Lower	0.7
		25%	Germanium	Similar	Lower	0.7
		50%	Indium	No substitute	No substitute	1
Solar components	8 %	25%	Silicon	Reduced	Lower	0.8
		25%	Zinc	Reduced	Lower	0.8
		50%	Indium	No substitute	No substitute	1
Low melting point alloys (soldering)	9 %	20%	Tin	Reduced	Lower	0.8
		80%	Indium	No substitute	No substitute	1

SP, SCr and SCo sub-parameters for Indium

End-use application	Share of main material in end-use applica-tion	Sub-shares of substitutes within end-use application	Substitute material	Substitute Production (SP)	Substitute Criticality (SCr)	Substitute Co-production (SCo)
Flat panel displays	70 %	5%	Tin	0.8	0.8	0.8
		5%	Zinc	0.8	0.8	0.8
		90%	Indium	1	1	1
Opto-electronic windows	9 %	25%	Tin	0.8	0.8	0.8
		25%	Zinc	0.8	0.8	0.8
		50%	Indium	1	1	1
Semiconductors	4 %	25%	Gallium	1	1	1
		25%	Germanium	1	1	1
		50%	Indium	1	1	1
Solar components	8 %	25%	Silicon	0.8	1	0.8
		25%	Zinc	0.8	0.8	0.8
		50%	Indium	1	1	1
Low melting point alloys (soldering)	9 %	20%	Tin	0.8	0.8	0.8
		80%	Indium	1	1	1

Existing substitutes for the main end-use applications of Tungsten

End-use application	Substitution possibilities	Substitute materials	Additional info
Cemented carbides (hardmetals)	W free carbides/cermets: titanium carbide; titanium carbonitride	Titanium	Manufacturer: VIRIAL (http://www.virial.ru/en/materials/199/)
	Ceramic matrix composite (CMC) materials-C/SiC or Si/SiC	Silicon	Manufacturer: VIRIAL (http://www.virial.ru/en/materials/199/)
	Ceramics based on zirconia (ZrO2)	Zirconium	Manufacturer: VIRIAL (http://www.virial.ru/en/materials/199/)
	Alumina (Al2O3) based ceramics	Aluminium	Manufacturer: VIRIAL (http://www.virial.ru/en/materials/199/)
Ttool/high speed steels	Molybdenum carbides	Molybdenum	http://www.imoa.info/molybdenum-uses/molybdenum-grade-alloy-steels-irons/tool-high-speed-steel.php http://www.totalmateria.com/page.aspx?ID=CheckArticle&site=kts&NM=236
Super-alloys (used in aircraft engines, marine vehicles, turbine blades, exhaust gas assemblies; furnace parts)	Mo alloys; ceramic matrix composite (CMC) materials-C/SiC or Si/SiC;	Molybdenum	http://www.geaviation.com/press/military/military_20150210.html
		Silicon	http://www.compositesworld.com/articles/ceramic-matrix-composites-heat-up http://americanmachinist.com/news/ge-starts-demo-testing-cmc-parts-jet-engines
Mill products (1) (electrodes, electrical and electronic contacts, wires, sheets, rods, heat sinks, radiation shielding, weights, ammunition and armour, in the automotive and aerospace industry, as furnace elements, jewellery, in medical and nuclear applications, for sports equipment and as welding electrodes. etc.)		Tantalum	http://www.hcstarck.com/en/products/technology_metals/tantalum.html; http://www.hcrosscompany.com/refractory/tantalum.htm http://www.grandviewmaterials.com/about/conflict
		Niobium	http://www.chinacarbide.com/En/Cpzx_List.asp?XcClassid=105103100; http://www.cbmm.com/us/p/173/uses-and-end-users-of-niobium.aspx
		Molybdenum	http://www.hcstarck.com/molybdenum_tzm_alloy
Mill products (2) Lighting	LED technology	Germanium	http://www.edisontechcenter.org/LED.html
		Silicon	http://www.edisontechcenter.org/LED.html

End-use application	Substitution possibilities	Substitute materials	Additional info
Mill products (2) Lighting	LED technology	Galium	http://www.edisontechcenter.org/LED.html
		Indium	http://www.itia.info/lamp-industry.html
		Europium	http://www.edisontechcenter.org/LED.html
		Terbium	http://www.ledsmagazine.com/articles/print/volume-8/issue-2/features/led-phosphor-suppliers-are-affected-by-china-s-rare-earth-export-quotas-magazine.html
		Yttrium	http://www.edisontechcenter.org/LED.html
Chemistry and others (high temperature lubricant and is a component of catalysts for hydrodesulfurization)		Molybdenum	Hydrotreatment and hydrocracking of oil fractions: ISBN 978-0-444-50214-9 Lubricants and Lubrication: ISBN 978-3-527-31497-3 http://www.belray.com/molylube-high-temperature-grease

SCP assessments for the identified substitutes for Tungsten

End-use application	Shares of main material in end-use application	Sub-shares of substitutes within end-use application	Substitute material	Substi-tute Perfor-mance (SP)	Substitute Cost (SC)*	SCP (matrix evaluation)
Cemented carbides (hardmetals)	60%	12.5%	Titanium	Similar	Lower	0.7
		12.5%	Silicon	Reduced	Lower	0.8
		12.5%	Zirconi um	Reduced	Higher (>2 times)	1
		12.5%	Aluminium	Reduced	Lower	0.8
		50%	Tungsten	No substitute	No substitute	1
Ttool/high speed steels	13%	50%	Molybdenum	Similar	Lower	0.7
		50%	Tungsten	No substitute	No substitute	1
Super-alloys	6%	25%	Molybdenum	Reduced	Lower	0.8
		25%	Silicon	Reduced	Lower	0.8
		50%	Tungsten	No substitute	No substitute	1
Mill products (1)	10%	16.7%	Tantalum	Reduced	Higher (>2 times)	1
		16.7%	Niobium	Reduced	Similar	0.8
		16.7%	Molybdenum	Reduced	Lower	0.8
		50%	Tungsten	No substitute	No substitute	1
Mill products (2) Ligthing	4%	7.14%	Germanium	Similar	Higher (>2 times)	0.9
		7.14%	Silicon	Similar	Lower	0.7
		7.14%	Galium	Similar	Higher (>2 times)	0.9
		7.14%	Indium	Similar	Higher (>2 times)	0.9
		7.14%	Europium	Similar	Higher (>2 times)	0.9
		7.14%	Terbium	Similar	Higher (>2 times)	0.9
		7.14%	Yttrium	Similar	Higher (>2 times)	0.9
		50%	Tungsten	No substitute	No substitute	1
Chemistry and others	7%	50%	Molybdenum	Reduced	Lower	0.8
		50%	Tungsten	No substitute	No substitute	1

SP, SCr and SCo sub-parameters for Tungsten

End-use application	Shares of main material in end-use application	Sub-shares of substitutes within end-use application	Substitute material	Substitute Production (SP)	Substitute Criticality (SCr)	Substitute Co-production (SCo)
Cemented carbides (hardmetals)	60%	12.5%	Titanium	0.8	0.8	0.8
		12.5%	Silicon	0.8	1	0.8
		12.5%	Zirconium	0.8	0.8	0.8
		12.5%	Aluminium	0.8	0.8	0.8
		50%	Tungsten	1	1	1
Ttool/high speed steels	13%	50%	Molybdenum	0.8	0.8	0.9
		50%	Tungsten	1	1	1
Super-alloys	6%	25%	Molybdenum	0.8	0.8	0.9
		25%	Silicon	0.8	1	0.8
		50%	Tungsten	1	1	1
Mill products (1)	10%	16.7%	Tantalum	1	0.8	1
		16.7%	Niobium	1	1	1
		16.7%	Molybdenum	0.8	0.8	0.9
		50%	Tungsten	1	1	1
Mill products (2) Ligthing	4%	7.14%	Germanium	1	1	1
		7.14%	Silicon	0.8	1	0.8
		7.14%	Galium	1	1	1
		7.14%	Indium	1	1	1
		7.14%	Europium	1	1	1
		7.14%	Terbium	1	1	1
		7.14%	Yttrium	1	1	1
		50%	Tungsten	1	1	1
Chemistry and others	7%	50%	Molybdenum	0.8	0.8	0.9
		50%	Tungsten	1	1	1

Trade barriers / Trade agreements: worked example for Lithium

Lithium										
Previous HHI-WGI (scaled) = 0.8342										
Country	Share of global production (2010)	$(Share*100)^2$	WGI_{scaled}	HHI-WGI	ER*	Details on ER	TA/EU member	Details on TA	t	HHI-WGI(t)
Chile	0.47	2209.00	2.58	5699.22	0	NA	0	NA	1	5,699.22
Australia	0.22	484.00	1.74	842.16	0	No export restrictions	0	NA	1	842.16
Argentina	0.16	256.00	5.43	1390.08	1.1	Export tax of 5% imposed in 2010	0	NA	1.1	1,529.09
USA	0.07	49.00	2.53	123.97	0	NA	0	NA	1	123.97
China	0.06	36.00	6.18	222.48	0	NA	0	NA	1	222.48
Brazil	0.01	1.00	4.73	4.73	0	NA	0	NA	1	4.73
Portugal	0.01	1.00	3.15	3.15	NA	NA	0.8	EU Member	0.8	2.52
Total										**8,424.17**
New HHI-WGI (scaled) = total HHI-WGI(t) / 10000 = 0.8424										

Trade barriers / Trade agreements: worked example for Indium

Previous HHI-WGI (scaled) = 2.1962										
Country	Share of global production (2011)	$(Share * 100)^2$	WGI_{scaled}	HHI-WGI	ER*	Details on ER	TA/EU member	Details on TA	t	HHI-WGI(t)
Belgium	0.045	20.250	2.26	45.765	NA	NA	0.8	EU Member	0.8	36.61
Brazil	0.007	0.490	4.73	2.3177	0	NA	0	NA	1	2.32
Canada	0.113	127.690	1.76	224.7344	0	NA	0	NA	1	224.73
China	0.574	3294.760	6.18	20361.617	1.22	Export quota of 233 tonnes	0	NA	1.22	24,841.17
Germany	0.015	2.250	2.16	4.86	NA	NA	0.8	EU Member	0.8	3.89
Italy	0.007	0.490	3.96	1.9404	NA	NA	0.8	EU Member	0.8	1.55
Japan	0.105	110.250	2.66	293.265	0	NA	0	NA	1	293.27
Netherlands	0.007	0.490	1.58	0.7742	NA	NA	0.8	EU Member	0.8	0.62
Republic of Korea	0.105	110.250	3.47	382.5675	0	NA	0	NA	1	382.57
Russian Federation	0.007	0.490	6.48	3.1752	1.1	NA	0	NA	1.1	3.49
Peru	0.003	0.090	5.37	0.4833	0	NA	0	NA	1	0.48
Others	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total										**25,790.70**
New HHI-WGI (scaled) = total HHI-WGI(t) / 10000 = 2.5790										

Trade barriers / Trade agreements: worked example for Tungsten

Country	Share of global production (2010)	(Share*100)^2	WGI scaled	HHI-WGI	ER*	Details on ER	TA/EU member	Details on TA	t	HHI-WGHI(t)
Previous HHI-WGI (scaled) = 4.5132										
Bolivia	0.02	4.000	6.07	24.28	0	NA	0	NA	1	24.28
Vietnam	0.01	1.000	6.10	6.1	1.1	Export tax of 20% imposed in 2010	0	NA	1.1	6.71
Austria	0.01	1.000	2.03	2.03	NA	NA	0.8	EU Member	0.8	1.62
China	0.85	7225.0	6.18	44650.5	1.1	Export tax of 20% imposed in 2010	0	NA	1.1	49,115.55
Rwanda	0.01	1.000	5.42	5.42	0	NA	0	NA	1	5.42
Portugal	0.01	1.000	3.15	3.15	NA	NA	0.8	EU Member	0.8	2.52
Peru	0.01	1.000	5.37	5.37	0	NA	0	NA	1	5.37
Thailand	0.01	1.000	5.58	5.58	0	NA	0	NA	1	5.58
Canada	0.01	1.000	1.76	1.76	0	NA	0	NA	1	1.76
Russian Federation	0.04	16.000	6.48	103.68	1.1	Export tax of 10% imposed in 2010	0	NA	1.1	114.05
Total										**49,282.86**
New HHI-WGI (scaled) = total HHI-WGI(t) / 10000 = 4.9282										

Flow accounting options to calculate End of life recycling input rate (EOL-RIR) using the MSA study.

EOL-RIR is calculated as:

$$EOL - RIR = \frac{Input\ of\ secondary\ material\ to\ EU\ [from\ old\ scrap]}{Input\ of\ primary\ material\ to\ EU + Input\ of\ secondary\ material\ to\ EU}$$

Still there are some options when accounting for input of primary material and input of secondary material from the MSA study.

When using the UNEP report there are not such options, because it is a world-based calculation and, subsequently, there are no import / export flows.

Selection of flows:

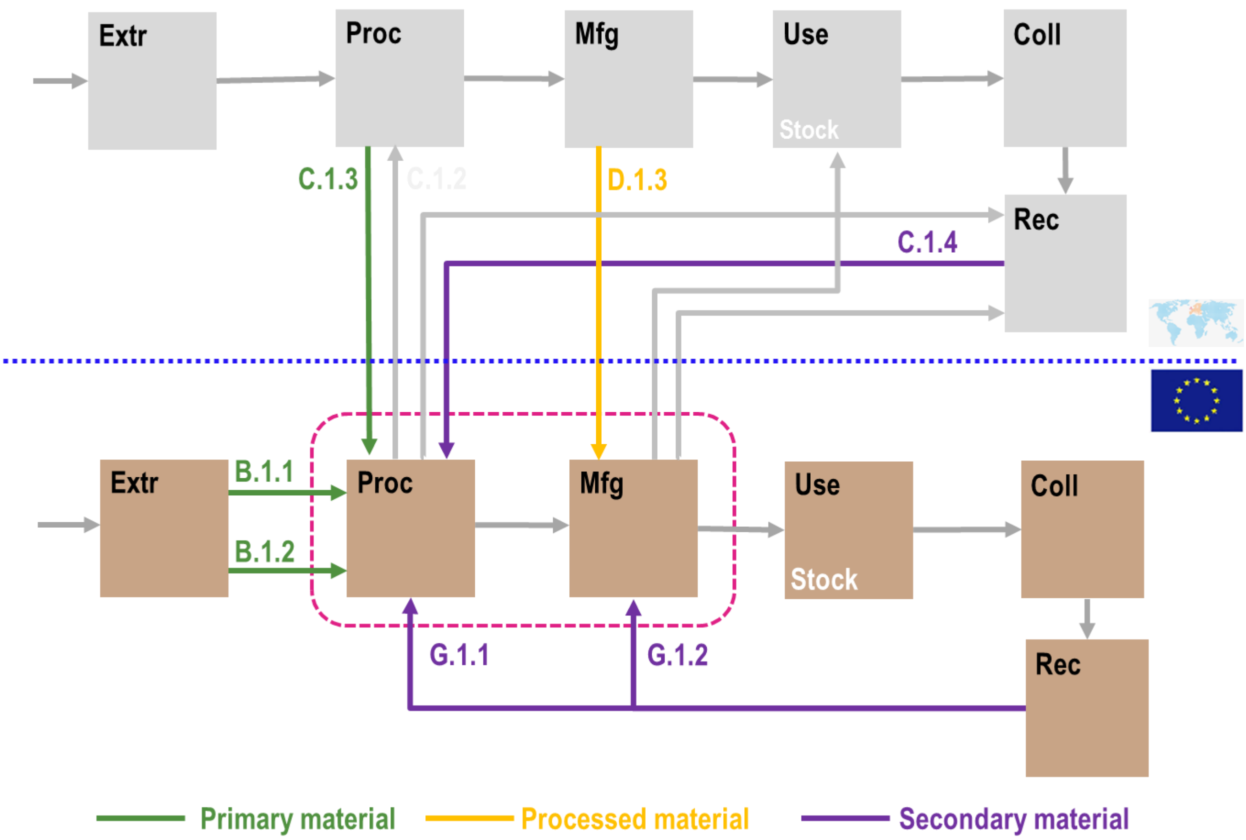
The underlying assumption is that the entire gross import of raw materials is beneficial to EU targets, eg. GDP of manufacturing up to 20%, even though they leave the EU at the processing stage, thus reducing the potential to generate added value and jobs downstream. Imports of secondary materials from ROW are accounted as part of the input of primary materials (denominator).

In the following diagram, the life cycle of a raw material in Europe is represented by the brown boxes while the first part of the figure represents the life cycle of a raw material in the rest of world (ROW). The colour code of the flows is the same as that for the MSA study. Green flows refer to primary material, yellow flows to processed material, and purple flows are secondary materials.

The flows considered are:

B.1.1. *Production of primary material as main product in EU sent to processing in EU;*
B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU;*
C.1.2 *Exports from EU of processed material;*
C.1.3 *Imports to EU of primary material;*
C.1.4. *Import to the EU of secondary materials;*
D.1.3 *Imports to EU of processed material;*
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU;*
G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU.*

Selected flows: the underlying asumption is that the entire gross import of raw materials are beneficial to EU targets, eg. GDP of manufacturing up to 20%, even though they leave the EU at the processing stage, thus reducing the potential to generate added value and jobs downstream. Imports of secondary materials from ROW are accounted as part of the input of primary materials (denominator).



$$EOL - RIR_C = \frac{G.1.1 + G.1.2}{B.1.1 + B.1.2 + C.1.3 + D.1.3 + C.1.4 + G.1.1 + G.1.2}$$

Where the MSA flows accounted for are:

B.1.1. *Production of primary material as main product in EU sent to processing in EU;*
B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU;*
C.1.3 *Imports to EU of primary material;*
C.1.4. *Import to the EU of secondary materials;*
D.1.3 *Imports to EU of processed material;*
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU;*

G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU.*

EOL-RIR in the 2014 EC criticality study and calculated using MSA and UNEP data.

Materials	EC study 2014	MSA study 2015	UNEP report 2011
Aggregates	n.i	7	n.i
Aluminium	35	-	16
Antimony	11	28	7
Barytes	0	-	n.i
Bauxite	0	-	n.i
Bentonite	0	-	n.i
Beryllium	19	0	8
Borate	0	1	n.i
Chromium	13	21	13
Clays	0	-	n.i
Cobalt	16	35	16
Coking coal	0	0	n.i
Copper	20	-	15
Diatomite	0	-	n.i
Feldspar	0	-	n.i
Fluorspar	0	1	n.i
Gallium	0	0	0
Germanium	0	2	9
Gold	25	-	23
Gypsum	1	-	n.i
Hafnium	0	-	n.d.
Indium	0	0	0
Iron	22	-	24
Limestone	0	-	n.i
Lithium	0	0	0
Magnesite	0	2	n.i
Magnesium	14	13	14
Manganese	19	-	19
Molybdenum	17	-	17
Natural Graphite	0	3	n.i
Natural Rubber	0	-	-
Nickel	32	-	26
Niobium	11	0	11
Perlite	0	-	n.i
Phosphate Rock	0	17	n.i
Potash	0	-	n.i
Pulpwood	51	-	n.i
Rhenium	13	-	9
Sawn Softwood	9	-	n.i
Scandium	1	-	n.d.
Selenium	5	-	n.d.

Materials	EC study 2013	MSA study 2015	UNEP report 2011
Silica sand	24		n.i
Silicon	0	0	n.i
Silver	24	-	21
Talc	0	-	n.i
Tantalum	4	-	3
Tellurium	0	-	n.d.
Tin	11	-	11
Titanium	6	-	6
Tungsten	37	42	37
Vanadium	0	-	n.d.
Zinc	8	-	9
PGMs	35	-	-
Platinum		11	23
Palladium		9	40
Rhodium		9	32
Ruthenium		-	11
Iridium		-	14
Osmium		-	
REE (Heavy)	0	-	-
Terbium		22	
Dysprosium		0	
Erbium		0	
Yttrium		31	
REE (Light)	0	-	-
Lanthanum		-	
Cerium		-	
Praseodymium		-	
Neodymium		1	
Samarium		-	
Europium		38	
Gadolinium		-	

n.d: no data available; n.i.: not included.

Recycling: worked examples using MSA data

Antimony - *All quantities in kilograms of antimony*	
Secondary materials (old scrap)	
G.1.1 Production of secondary material from post-consumer functional recycling in EU sent to processing in EU	$9.70 \cdot 10^{6}$
G.1.2 Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU	0
Primary and processed materials	
B.1.1. Production of primary material as main product in EU sent to processing in EU	0
B.1.2. Production of primary material as by product in EU sent to manufacturing in EU	0
C.1.3 Imports to EU of primary material	$4.56 \cdot 10^{5}$
C.1.4 Imports to EU of secondary material	$1.75 \cdot 10^{4}$
D.1.3 Imports to EU of processed material	$2.46 \cdot 10^{7}$

$$EOL - RIR_{Sb} = \frac{9.70 \cdot 10^{6}}{9.70 \cdot 10^{6} + 4.56 \cdot 10^{5} + 1.75 \cdot 10^{4} + 2.46 \cdot 10^{7}}$$

$$EOL - RIR_{Sb} = \frac{9.70 \cdot 10^{6}}{3.48 \cdot 10^{7}} = 0.279$$

Chromium - *All quantities in kilograms of chromium*	
Secondary materials (old scrap)	
G.1.1 Production of secondary material from post-consumer functional recycling in EU sent to processing in EU	$3.83 \cdot 10^{8}$
G.1.2 Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU	0
Primary and processed materials	
B.1.1. Production of primary material as main product in EU sent to processing in EU	$2.79 \cdot 10^{8}$
B.1.2. Production of primary material as by product in EU sent to manufacturing in EU	0
C.1.3 Imports to EU of primary material	$8.02 \cdot 10^{8}$
C.1.4 Imports to EU of secondary material	$9.01 \cdot 10^{7}$
D.1.3 Imports to EU of processed material	$2.78 \cdot 10^{8}$

$$EOL - RIR_{Cr} = \frac{3.83 \cdot 10^{8}}{3.83 \cdot 10^{8} + 2.79 \cdot 10^{8} + 8.02 \cdot 10^{8} + 9.01 \cdot 10^{7} + 2.78 \cdot 10^{8}}$$

$$EOL - RIR_{Cr} = \frac{3.83 \cdot 10^{8}}{1.83 \cdot 10^{9}} = 0.209$$

Cobalt - *All quantities in kilograms of cobalt*	
Secondary materials (old scrap)	
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU*	$6.32 \cdot 10^6$
G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU*	0
Primary and processed materials	
B.1.1. *Production of primary material as main product in EU sent to processing in EU*	0
B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU*	$1.27 \cdot 10^6$
C.1.3 *Imports to EU of primary material*	$1.02 \cdot 10^7$
C.1.4 *Imports to EU of secondary material*	0
D.1.3 *Imports to EU of processed material*	$5.61 \cdot 10^5$

$$EOL - RIR_{\ Co} = \frac{6.32 \cdot 10^6}{6.32 \cdot 10^6 + 1.27 \cdot 10^6 + 1.02 \cdot 10^7 + 5.61 \cdot 10^5}$$

$$EOL - RIR_{\ Co} = \frac{6.32 \cdot 10^6}{1.83 \cdot 10^7} = 0.345$$

Germanium - *All quantities in kilograms of germanium*	
Secondary materials (old scrap)	
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU*	0
G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU*	$1.21 \cdot 10^3$
Primary and processed materials	
B.1.1. *Production of primary material as main product in EU sent to processing in EU*	0
B.1.2. *Production of primary material as by product in EU sent to manufacturing in EU*	0
C.1.3 *Imports to EU of primary material*	$5.05 \cdot 10^4$
C.1.4 *Imports to EU of secondary material*	$3.27 \cdot 10^2$
D.1.3 *Imports to EU of processed material*	$1.75 \cdot 10^4$

$$EOL - RIR_{\ Ge} = \frac{1.21 \cdot 10^3}{1.21 \cdot 10^3 + 5.50 \cdot 10^4 + 3.27 \cdot 10^2 + 1.75 \cdot 10^4}$$

$$EOL - RIR_{\ Ge} = \frac{1.21 \cdot 10^3}{6.95 \cdot 10^4} = 0.017$$

Indium - ***All quantities in kilograms of indium***	
Secondary materials (old scrap)	
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU*	$2.00 \cdot 10^{2}$
G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU*	0
Primary and processed materials	
B.1.1. Production of primary material as main product in EU sent to processing in EU	0
B.1.2. Production of primary material as by product in EU sent to manufacturing in EU	$9.91 \cdot 10^{4}$
C.1.3 *Imports to EU of primary material*	$1.72 \cdot 10^{4}$
C.1.4 *Imports to EU of secondary material*	$8.31 \cdot 10^{3}$
D.1.3 Imports to EU of processed material	$6.13 \cdot 10^{4}$

$$\rho_{In} EOL - RIR_{\ In} = \frac{2.00 \cdot 10^2}{2.00 \cdot 10^2 + 9.91 \cdot 10^4 + 1.72 \cdot 10^4 + 8.31 \cdot 10^3 + 6.13 \cdot 10^4}$$

$$EOL - RIR_{\ In} = \frac{2.00 \cdot 10^2}{1.86 \cdot 10^5} = 0.001$$

Lithium - ***All quantities in kilograms of lithium carbonate equivalent (LCE)***	
Secondary materials (old scrap)	
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU*	0
G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU*	0
Primary and processed materials	
B.1.1. Production of primary material as main product in EU sent to processing in EU	$1.87 \cdot 10^{6}$
B.1.2. Production of primary material as by product in EU sent to manufacturing in EU	0
C.1.3 *Imports to EU of primary material*	$7.18 \cdot 10^{6}$
C.1.4 *Imports to EU of secondary material*	0
D.1.3 Imports to EU of processed material	$1.42 \cdot 10^{7}$

$$EOL - RIR_{\ LCE} = \frac{0}{1.87 \cdot 10^6 + 7.18 \cdot 10^6 + 1.42 \cdot 10^7} = \frac{0}{2.32 \cdot 10^7}$$

$$EOL - RIR_{LCE} = 0$$

Tungsten - All quantities in kilograms of tungsten	
Secondary materials(old scrap)	
G.1.1 *Production of secondary material from post-consumer functional recycling in EU sent to processing in EU*	$2.63 \cdot 10^6$
G.1.2 *Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU*	$7.60 \cdot 10^6$
Primary and processed materials	
B.1.1. Production of primary material as main product in EU sent to processing in EU	$8.69 \cdot 10^5$
B.1.2. Production of primary material as by product in EU sent to manufacturing in EU	0
C.1.3 Imports to EU of primary material	$2.58 \cdot 10^6$
C.1.4 *Imports to EU of secondary material*	$7.26 \cdot 10^4$
D.1.3 Imports to EU of processed material	$1.09 \cdot 10^7$

$$\rho_W = EOL - RIR_{\,W} = \frac{2.63 \cdot 10^6 + 7.60 \cdot 10^6}{2.63 \cdot 10^6 + 7.60 \cdot 10^6 + 8.69 \cdot 10^5 + 2.58 \cdot 10^6 + 7.26 \cdot 10^4 + 1.09 \cdot 10^7}$$

$$EOL - RIR_{\,W} = \frac{1.02 \cdot 10^7}{2.46 \cdot 10^7} = 0.415$$

Recycling: worked examples using UNEP data

Aluminium - All quantities in percentage	
Old scrap ratio (average)	*45*
Working group consensus	40
Zheng, 2009	50
Recycled content ratio (average)	*35*
Plunkert (USGS, 2006)	34
Working group consensus	36
Zheng, 2009	36

Zheng, L. 2009. Organisation of European Aluminium refiners and remelters, Private communication.
Plunkert, P.A. 2006. Aluminum recycling in the United States in 2000. USGS Circular 1196-W.

$$EOL - RIR_{Al} = OSR \times RC = 0.45 \times 0.35 = 0.16$$

Copper - All quantities in percentage	
Old scrap ratio (average)	***51***
Goonan (USGS 2010)	24
Graedel et al., 2004	78
Recycled content ratio (average)	***29***
Graedel et al., 2004	20
Goonan (USGS, 2010)	30
Risopatron, 2009	37

Goonan, T.G. 2010. Copper recycling in the United States in 2004. USGS Circular 1196-X.
Graedel, T.E. D. Van Beers, M. Bertram, K. Fuse, R.B. Gordon, A. Gritsinin, E. Harper, A. Kapuer, R.J. Klee, R.J. Lifset, L. Memon, J. Rechberger, S. Spatari, and D. Vexler. 2004. The multilevel cycle of anthropogenic copper. Environmental Science and Technology, 38: 1253-1261.
Risopatron, C.R. 2009. The case of copper, paper presented at Eurometaux workshop on metal recycling data, Brussels, June 4.

$$EOL - RIR_{Cu} = OSR \times RC = 0.51 \times 0.29 = 0.15$$

Tantalum - All quantities in percentage	
Old scrap ratio (average)	***18***
Expert opinion	1-10
Cunningham, 2004	43
Recycled content ratio (average)	***19***
Expert opinion	10-25
Cunningham, 2004	21

Cunningham, L.D. 2004. Tantalum recycling in the United States in 1998. USGS Circular 1196-Z.

$$EOL - RIR_{Ta} = OSR \times RC = 0.18 \times 0.19 = 0.03$$

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